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ORIGINAL ARTICLE

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Effect of Sunlight Exposure and Packaging Materials on the Quality and Oxidative Stability of Commercial Vegetable Oils in Cameroon

Fabrice Tonfack Djikeng [1] ✉ **L. Felicite Fenyom Tuete** [2] **Franklin Kegah Ngoualem** [3] **Hilaire Macaire Womeni** [4]

1 Department of Biology and Molecular Biology, Faculty of Science, University of Buea PO Box 63, Buea, Cameroon tonfack.fabrice@ubuea.cm
2 Chartered Higher Institute of Technology and Management, School of Home Economics, Tourism and Hotel Management. PO Box 63, Buea, Cameroon luciennefenyom@gmail.com
3 Faculty of Agriculture and Veterinary Medicine, University of Buea, PO Box 63, Buea, Cameroon ngoualson@gmail.com
4 Department of Biochemistry, Faculty of Science, University of Dschang, P.O BOX 67, Dschang, Cameroon, womeni@yahoo.fr

ABSTRACT

Background: In Cameroon, edible oils are commonly packaged in translucent 1L polyethylene bottles and opaque 5L, 10 L, and 20L polyethylene containers. The translucent packaging is often favored by customers due to product visibility, potentially influencing purchasing decisions. However, in local markets, these oils are frequently exposed to direct sunlight throughout the day for display purposes until sail. Such exposure can compromise oil quality and pose potential health risks to consumers.

Aims: The study aimed to evaluate the impact of ambient and direct sunlight storage conditions, as well as different packaging materials, on the quality and oxidative stability of palm olein, palm oil, and soybean oil.

Methods: Palm oil, palm olein and soybean oil were selected for this study. Approximately 2.5 L of each oil was aliquoted into three portions: two 1.2 L portions for experimental storage and one 0.1 L portion to serve as an initial control. Each of the two 1.2 L experimental portions was further subdivided into nine 130 mL aliquots and transferred into three types of packaging: translucent polyethylene bottles (TPEB), non-translucent polyethylene bottles (NTPB), and brown dark glass bottles (BDGB). One set of nine packaged aliquots was stored in dark ambient conditions, while the other set was exposed to direct solar radiation for 8 hours daily over a 30-day period. Samples from both storage conditions were collected every 10 days for analysis of quality and stability parameters, including color, peroxide value, p-Anisidine value, TOTOX value, thiobarbituric acid reactive substances (TBARS), acid values, and Fourier Transformed Infrared (FTIR) Spectroscopy.

Results: Our findings indicate that sunlight significantly reduced the L* and b* color values of palm oil. Furthermore, exposure to sunlight markedly increased the peroxide, p-anisidine, TOTOX, and thiobarbituric acid values in all analyzed oil samples compared to those stored in dark ambient conditions. This increase was most pronounced in soybean oil, likely attributable to its higher content of polyunsaturated fatty acids. Notably, the palm oil extraction process significantly elevated its initial acidity. FTIR spectra revealed minor differences, with soybean oil exhibiting the most significant alterations. Both BDGB and NTPB demonstrated superior protection of the tested oils' quality under sunlight exposure compared to TPEB.

Conclusions: Based on these findings, we recommend that edible oils sold in the market be packaged in NTPB or BDGB so as to effectively reduce the adverse effects of direct sunlight and limit photo-oxidative reactions. Furthermore, storing oils should under dark ambient conditions is crucial to prevent degradation caused by photo-oxidation.

Keywords: Palm oil, Soybean oil, Palm olein, Packaging material, Sunlight, Oxidation.

ARTICLE INFORMATION

✉ **Corresponding author: Tonfack** D. Fabrice
E-mail: fdjikeng@gmail.com
Tel. +237 696 368 059

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1 INTRODUCTION

Oils and fats, derived from animal and plant sources, constitute essential components of the human diet. Comprising approximately 98% of triglycerides, they are routinely utilized in food preparation and seasoning due to their distinctive nutritional and technological properties. From a nutritional standpoint, these lipids serve as vital sources of fat-soluble vitamins (A, D, E, and K) and essential fatty acids (Walisiewicz-Niekbalska *et al.*, 1997). These essentials fatty acids which are linoleic and alpha- linolenic acids, together with other omega -3 and -6 fatty acids such as

arachidonic acid, eicosapentaenoic acid and docosahexaenoic acid are recognized for their beneficial roles in human health, including anticancer, antibacterial, anti-inflammatory, and regulatory effects on blood pressure and cholesterol levels (Charanyaa *et al.*, 2019; Jacob, 2016; Li, 2015). Technologically, oils and fats function as heat transfer mediums during frying and enhance the organoleptic properties of food by retaining flavors (Dehghannya and Ngadi, 2021). However, during processing or suboptimal storage conditions, their quality can significantly deteriorate due to lipid oxidation reactions, a process particularly prevalent in oils rich in polyunsaturated fatty acids (PUFA).

Lipid oxidation, defined as a series of chemical reactions, negatively impacts food quality and shelf-life. This oxidation reaction reduces the nutritional value of food by decreasing fat-soluble vitamins, essential fatty acids, and amino acids, as well as a reduction in protein digestibility. This process also impairs the sensory characteristics of food through the formation of volatile substances such as aldehydes and ketones, which are responsible of rancid odors (Cuvelier and Maillard 2012). Products of lipid oxidation such as reactive oxygen species, hydroperoxides, aldehydes, and ketones have been associated with an increased risk of various disorders including cardiovascular diseases, cancer, genetic mutations, and accelerated aging (Sikwese and Duodu, 2007). Several factors are involved in the promotion of lipid oxidation reactions in oils and fats among which the storage conditions, processing methods, packaging materials oxygen availability, and the presence or absence of antioxidants (Djikeng *et al.*, 2018). Among the three recognized types of lipid oxidation exist—autooxidation, photooxidation, and enzymatic oxidation—photooxidation is notably faster and more detrimental, reported to be 1500 times more rapid (Cuppett *et al.*, 1997). This light-catalyzed reaction involves highly electrophilic singlet oxygen, which directly reacts with unsaturated fatty acids to form hydroperoxydes. The subsequent decomposition of these hydroperoxides leads to the formation of aldehydes, ketones, and other compounds responsible for undesirable off-odors in foods (Aruoma and Cuppett, 1997). This type of oxidation is known to occur in oils exposed to both natural and artificial light.

In Cameroon, a diverse array of edible oils is commercialized, especially in local markets, including palm oil, palm olein, palm kernel oil, soybean oil, sunflower oil, cottonseed oil, coconut oil, and sesame oil. Among these, palm oil, palm olein, and soybean oil are the most widely available, sold, and consumed, with palm oil and palm olein being highly sought after due to their affordability. Driven by limited shop space and marketing strategies aimed at attracting customers, these oils are routinely exposed to direct sunlight throughout the day. Such improper handling can lead to photooxidation initiated by UV radiation in sunlight, resulting in the formation of deleterious substances that, upon consumption, may contribute to conditions such as cancer, cardiovascular diseases, and genetic mutations (Anwar *et al.*, 2007). It is pertinent to note that the chemical composition of an oil significantly influences its susceptibility to photooxidation. Oils rich in PUFA are reported to oxidize more readily than those abundant in monounsaturated fatty acids, which, in turn, oxidize more easily than oils rich in saturated fatty acids (Maszewska *et al.*, 2018). The presence or absence of natural antioxidants also affects oil stability under photooxidation conditions. For instance, soybean oil typically comprises 50–60% linoleic acid, 20–30% oleic acid, 6–10% of palmitic acid, and 5–10% of linolenic acid (Wan Ghazali *et al.*, 2015). Conversely, palm oil and its liquid fraction, palm olein, are semi-solid oils containing approximately 50% saturated fatty acids and 50% unsaturated fatty acids, with palmitic (44%), stearic (5%), oleic (40%), and linoleic (11%) acids being the most prevalent. Additionally, palm oil is rich in fat soluble vitamins (vitamin A and E at concentrations of 500 and 800 ppm, respectively) (Goh *et al.*, 1985). These compositional differences can lead to varying oxidation behaviors among these oils. Additionally, the type of packaging material exerts a significant impact on oil quality and stability. Previous research indicates reported that glass bottles offer superior protection against oil oxidation compared to polyethylene (PET) bottles. Oxidation proceeds faster in packages stored in light than in darkness and in those with headspace, with the best oil quality observed when stored in the dark, free of air, and packed in glass, followed by PET (Kucuk and Carner, 2005). Similarly, Dabbou *et al.* (2011) demonstrated that oil and fat quality indexes are strongly influenced by packaging type and the storage duration, highlighting stainless steel and dark glass bottles as most adequate for oil preservation.

In Cameroon, the edible oil industry typically packages vegetable oils in both translucent polyethylene bottles (for 1 L, 5 L, and 10 L containers) and non-translucent polyethynele bottles (5 L, 10 L, and 20 L). As noted, in local markets, a considerable proportion of these oils are exposed to solar radiations daily, this either for consumer attraction or due to limited retail space (Anwar *et al.*, 2007). Such practices carry the risk of photooxidation by UV radiation, leading to the formation of hazardous substances that, upon consumption, can contribute to severe health issues such as cancer, cardiovascular diseases, and mutations (Sikwese and Duodu, 2007). Despite the prevalence of these practices and their potential health implications, there is a distinct lack of studies in Cameroon evaluating the protective effect of different packaging materials used by the oil industry during storage of oils under sunlight and dark ambient conditions on the physicochemical characteristics of oils. Prior reports indicate that non-communicable diseases (NCDs) account for an estimated 31% of all deaths in Cameroon, with cardiovascular diseases contributing 14% of these fatalities.

Annually, approximately 15000 new cancer cases are diagnosed in the country every year, equating to about 107 new cases per 100,000 inhabitants (45 males/62 females). The most common forms include breast cancer (18.5%), cervical cancer (13.8%), prostate cancer (7.3%), liver cancer (2.9%), and colorectal cancer (2.9%) (WHO, 2014). The rising incidence of these NCDs could partly be attributed to dietary factors, given that the processing and handling of daily consumed foods, especially oils and fats often lead to the generation of toxic substances. While several studies have investigated the impact of various storage conditions on ail and fat quality (Charanyaa *et al.*, 2019; Kishimoto, 2019; Houshia *et al.*, 2019; Zeb *et al.*, 2008), there remains a notable gap in research specifically examining the combined impact of packaging material type and storage conditions on oil quality of oils within the Cameroonian context.

Consequently, there is an imperative need to evaluate the influence of different storage conditions and packaging materials on the quality and stability of palm oil, palm olein, and soybean oil produced, commercialized, and consumed in Cameroon. Such an evaluation will provide critical information to the population regarding optimal practices for preserving oil quality and safeguarding their health. It is hypothesized that the storage of edible oils under direct sunlight in translucent polyethylene bottles will significantly compromise their quality and stability compared to storage in non–translucent bottles and under dark ambient conditions. Therefore, the objective of this study was to evaluate the effect of storing palm olein, palm oil, and soybean oil under sunlight and ambient dark conditions, considering various packaging material types, on their overall quality and stability.

2 Materials and Methods

2.1 Materials

Palm oil was purchased from farmers directly after extraction from the Lebialem Division, South-West Region of Cameroon. Refined palm olein and soybean oil were purchased from the Santa Lucia supermarket, Douala, Littoral Region of Cameroon. Only freshly manufactured oils were utilized. For the refined oils, a shelf-life of two years from the manufacturing date was indicated by the producer. These refined oils were enriched with Vitamin E and fortified with Vitamin A. Crude palm oil, known for its inherent richness in vitamins A and E and its notable stability, was employed. No oil blends were used in this study. The oils were initially purchased in 1 L translucent plastic bottles. The translucent polyethylene bottles, non-translucent white polyethylene bottles, and dark brown bottles used for packaging were acquired from Mboppi market, Douala, Littoral region of Cameroon. All chemicals and reagents utilized were of analytical grade. Ammomium thiocyanate was purchased from Finar chemicals limited (Ahmedabad, India). Purified anhydrous sodium sulfate, p-anisidine (99%), ferrous sulfate, baryum chloride, ferric chloride, hydrochloric acid (35%), and sulfuric acid (98%) were obtained from SD-fine chemicals limited (Ahmedabad, India). Isooctane and acetic acid were purchased from Finar Chemicals Limited (Ahmedabad, India); methanol from Avantor Performance Materials India Limited; and chloroforme from Thermo Fisher Scientific India Pvt Ltd (Mumbai, India).

2.2 Methods

2.2.1 Sample Preparation and Storage

Approximately 2.5 L of each oil was utilized. A 0.1 L aliquot of each oil was initially separated from the bulk container to serve as a control for measuring the baseline quality. The remaining 2.4 L of each oil was subsequently divided into two 1.2 L portions, designated for ambient dark storage and sunlight exposure, respectively. Each 1.2 L portion of oil was further divided into nine 130 mL aliquots. Three of these aliquots were introduced into translucent polyethylene bottles (TPEB), three into non- translucent polyethylene bottles (NTPEB), and the remaining three into brown dark glass bottles (BDGB).

One set of nine 130 mL oil aliquots (comprising oil type in each packaging material) was subjected to direct sunlight exposure for 30 days, with an 8-hour exposure period per day. A single bottle of each oil type in its respective packaging material was collected every 10 days for quality analysis. The second set was stored at ambient room temperature in the dark for 30 days, with samples collected at the same 10-day intervals for quality analysis.

For dark ambient storage, oil samples were maintained in a cupboard at room temperature (approximately 27 °C). For sunlight exposure, samples were subjected to ambient sunlight conditions, with temperatures ranging from 29.35–33.94°C. The oils were positioned on a table; replicating typical display practices observed in local markets. The experiment took place during the dry season in Cameroon, from December to January 2024, at the University of Buea, South-West Region, Cameroon. Oils exposed to sunlight were stored daily from 8:00 to 16:00 and subsequently transferred to a dark cupboard at room temperature during overnight until the next day's exposure. The average daily sunshine duration during the experimental period was 9 hours.

2.2.2 Physicochemical Properties of the Oil

Color Measurement

Changes in the color of oil samples during storage were quantified using a FRU WR10 Portable Colorimeter. The instrument was calibrated using an empty Petri dish placed on a white surface, and the blank value was recorded. Subsequently, oil was introduced into the Petri dish and scanned with the colorimeter. The blank value was subtracted from the measured test value, and the result recorded. Analyses were carried-out in triplicate. Results were expressed using the CIE Lab* color space parameters: L* is known as the lightness L* (lightness, where L*=0 is black and L*=100 is white), a* (greenness [-a*] to redness [+a*]), and b* (blueness [-b*] to yellowness [+b*]).

Quality Indices

Oil quality indices were determined using standard methods. The peroxide value (PV) was determined according to the IDF method (IDF, 1991). The p-anisidine value (p-AV) and acid value were determined following AOCS standard methods Cd 18–90 and Ca 5a–40, respectively (AOCS, 2003). The thiobarbituric acid reactive substances value was assessed using the method described by Draper and Hadley (1990). The TOTOX value was calculated using the equation proposed by Shahidi and Wanasundara (2008): TOTOX = 2PV + AV.

2.2.3 Fourier Transformed Infrared (FTIR) Spectroscopy

Fourier Transformed Infrared (FTIR) Spectroscopy of oil samples was performed using the technique described by Liang *et al.* (2013). A Shimadzu IRPrestige-21 spectrometer, equipped with a DLATGS detector, was utilized. Potassium bromide (KBr) was employed as the beam splitter. A 20 µL aliquots of each sample was deposited between two KBr disks to form a thin film, and spectra were recorded in the 4000–500 cm^{-1} IR region. Analyses were performed in triplicate, with clean, empty KBr disks serving as the blank. The KBr disks were meticulously cleaned twice with hexane, dried, then rinsed, and subsequently dried again prior to each measurement.

2.2.4 Statistical Analysis

All analyses were performed in triplicates. The obtained data (expressed as Mean ± Standard deviation) were subjected to one-way analysis of variance (ANOVA) using StatGraphics Centurion version XVI software to evaluate statistical significance. A probability value at $p < 0.05$ was considered statistically significant.

3 Results and Discussion

3.1 Physicochemical properties

3.1.1 Color

Color change serves as a key indicator of oil alteration. Variations in the color parameters of different oil samples, both before and after storage in various packaging materials, are presented in Table 1. A significant decrease ($p < 0.05$) in L* value was recorded for palm oil samples exposed to direct sunlight. This indicates a reduction in the oil's lightness, likely attributable to pigment oxidation (Li *et al.,* 2023). No significant change ($p > 0.05$) in the L* value was detected for the other oil types before and after storage, suggesting that their lightness-contributing pigments were not significantly affected. An increase in the a* value indicates a shift towards the red spectrum, while a decrease signifies a shift towards the green spectrum. Results revealed no significant difference ($p > 0.05$) in the a* value among palm oil, soybean oil, and palm olein. However, a significant decrease ($p < 0.05$) in the b* value was observed in samples following storage under direct sunlight. The b* scale represents yellowness when positive and blueness when negative. Consequently, the decrease in b* value indicates a reduction in yellow coloration, which can be attributed to the degradation of carotenoids and other yellow pigments via photo-oxidation reactions. Previous studies have reported that exposure of palm olein to sunlight significantly reduces its color intensity in both red (a*) and yellow (b*) units compared to the same oil stored under dark ambient conditions (Djikeng *et al.,* 2019).

3.1.2 Peroxide value

The peroxide value (PV) typically serves as an indicator of the primary oxidation state of oils and fats, characterized by the formation of hydroperoxides (Dodoo *et al.*, 2020). Changes in the peroxide value of oils samples under various storage conditions and packaging materials are presented in Figure1. Results demonstrated a significant increase ($p < 0.05$) in this parameter across nearly all samples throughout the storage period. Furthermore, PVs were significantly higher ($p < 0.01$) in oils exposed to direct sunlight compared to those stored under ambient conditions. This phenomenon can be attributed to the accelerated formation of hydroperoxides. The significantly higher peroxide values observed in oils exposed to sunlight, compared to those stored under dark ambient conditions, can be explained by the detrimental effect of sunlight-induced photooxidation. Sunlight, containing UV radiations, actively promote the photooxidation of edible oils and fats. This process involves

Table 1. Association of Sociodemographic Characteristics and Glycemic Control

Samples	Day 0			Day 30 Ambient storage			Day 30 Sunlight storage		
	L	a	B	L	a	b	L	a	b
Palm olein NTPB	59.31±0.00$^{a}_{A}$	3.01±0.07$^{a}_{A}$	-2.41±0.10$^{a}_{A}$	59.57±0.10$^{a}_{A}$	2.65±0.12$^{a}_{A}$	-2.59±0.02$^{a}_{A}$	59.99±002$^{a}_{A}$	2.71±0.02$^{a}_{A}$	-2.72±0.22$^{a}_{A}$
Palm olein TPEB	59.36±0.07$^{a}_{A}$	3.01±0.07$^{a}_{A}$	-2.50±0.22$^{a}_{A}$	60.75±0.00$^{a}_{A}$	2.50±0.02$^{a}_{A}$	-1.07±0.14$^{b}_{B}$	59.42±0.02$^{a}_{A}$	2.63±0.00$^{a}_{A}$	-2.59±0.20$^{a}_{A}$
Palm olein BDGB	59.36±0.06$^{a}_{A}$	3.06±0.00$^{a}_{A}$	-2.57±0.12$^{a}_{A}$	59.59±0.07$^{a}_{A}$	2.6±0.07$^{a}_{A}$	-1.64±0.39$^{b}_{B}$	58.64±0.02$^{a}_{A}$	2.64±0.07$^{a}_{A}$	-1.85±0.28$^{b}_{A}$
Soybean oil NTPB	59.26±0.58$^{a}_{A}$	3.04±0.04$^{a}_{A}$	-1.61±0.21$^{b}_{B}$	59.51±0.50$^{a}_{A}$	2.68±0.01$^{a}_{A}$	-2.44±0.28$^{a}_{A}$	60.13±0.16$^{a}_{A}$	2.77±0.04$^{a}_{A}$	-3.13±0.14$^{c}_{A}$
Soybean oil TPEB	59.23±0.62$^{a}_{A}$	3.02±0.02$^{a}_{A}$	-1.64±0.25$^{a}_{B}$	59.70±0.10$^{a}_{A}$	2.72±0.02$^{a}_{A}$	-2.35±0.12$^{b}_{B}$	59.52±0.17$^{a}_{A}$	2.76±0.00$^{a}_{A}$	-3.37±0.05$^{c}_{B}$
Soybean oil BDGB	58.82±0.04$^{a}_{A}$	3.06±0.02$^{a}_{A}$	-1.79±0.03$^{a}_{B}$	59.98±0.14a$_{A}$	2.68±0.01$^{a}_{A}$	-2.62±0.39$^{a}_{A}$	59.91±0.15$^{a}_{A}$	2.79±0.05$^{a}_{A}$	-2.50±0.07$^{a}_{A}$
Palm oil NTPB	69.16±0.03$^{a}_{A}$	7.49±0.03$^{b}_{B}$	10.22±0.38$^{a}_{C}$	68.12±0.03$^{a}_{B}$	7.43±0.03$^{b}_{B}$	10.24±0.38$^{a}_{C}$	49.56±0.34$^{b}_{A}$	7.45±0.08$^{b}_{B}$	5.35±0.51$^{b}_{C}$
Palm oil TPEB	69.30±0.23$^{a}_{B}$	7.47±0.00$^{b}_{B}$	10.22±0.38$^{a}_{C}$	69.21±0.23$^{a}_{A}$	7.34±0.00$^{b}_{B}$	10.26±0.38$^{a}_{C}$	49.59±0.34$^{b}_{B}$	7.57±0.08$^{b}_{B}$	5.36±0.51$^{b}_{C}$
Palm oil BDGB	69.33±0.19$^{a}_{B}$	7.49±0.03$^{b}_{B}$	10.49±0.00$^{a}_{C}$	69.42±0.19$^{a}_{B}$	7.41±0.03$^{b}_{B}$	10.22±0.00$^{a}_{C}$	49.66±0.34$^{b}_{B}$	7.51±0.08$^{b}_{B}$	5.44±0.51$^{b}_{C}$

Note: n=3. Data are presented as mean (± SD). $^{A-C}$ Values of the same column with different superscripts are significantly different at $p < 0.05$.$^{a-b}$ values of the same raw for the same parameter and with different superscripts are significantly different at $p < 0.05$. TPEB: Translucent polyethylene bottle; NTPB: Non translucent polyethylene bottle; BDGB: Brown dark glass bottles.

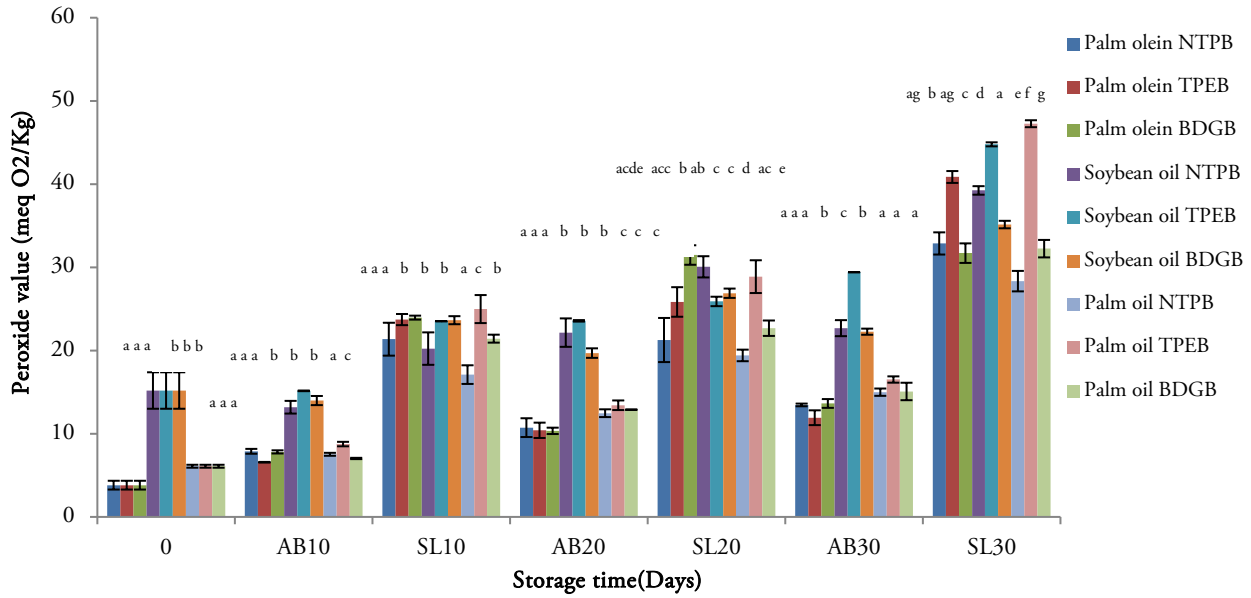

Figure 1. Changes in peroxide value of oil samples during storage. TPEB: Translucent polyethylene bottle; NTPB: Non translucent polyethylene bottle; BDGB: Brown dark glass bottles

Note: n=3. Data are presented as mean (± SD). $^{a-g}$ Values of the same storage day and conditions with different superscripts are significantly different at $p < 0.05$

singlet oxygen and PUFA, leading to the rapid formation of hydroperoxides through a reaction which is at least 1000 to 1500 times faster than autoxidation reactions (Cuppet *et al.*, 1997).

Results revealed that oil samples exposed to sunlight and stored in NTPB and BDGB exhibited significantly ($p < 0.05$) lower peroxide values compared to the identical oils stored in TPEB. This can be attributed to the easier access of solar radiation into the oil packaged in TPEB compared to the other packaging materials. In fact, the brown nature of BDGB likely played a significant role in mitigating the ingress of sunlight. These results align with the those of Iskanden *et al.* (2011), who reported that the peroxide value of sunflower oil was significantly lower in brown glass bottles compared to polyethylene bottles, and in turn, significantly lower than in colorless bottles, during nine (9) months of storage at ambient temperature.

A significant increase ($p < 0.05$) in peroxide value was observed in oils stored under sunlight compared to ambient conditions. This result corroborates the finding of Dodoo *et*

al. (2020) and Djikeng *et al.* (2019), who demonstrated significantly higher peroxide value in coconut oil, palm oil, palm kernel, and palm olein exposed to sunlight compared to those stored under ambient conditions. Furthermore, Kishimoto (2019) demonstrated that low-transparent packaging material offered superior protection to extra virgin olive oil against sunlight-induced oxidation during storage.

3.1.3 *p*-Anisidine Value

Primary oxidation products (hydroperoxides) can break down into secondary oxidation products (aldehydes, ketones, hydrocarbons, etc.), some of which can be detected using the p-anisidine test (2-alkenals, and 2,4-dienals) (Arranz *et al.*, 2008; Varlet *et al.*, 2007).

The variations in p-anisidine value of oil samples stored in the dark under ambient conditions, under sunlight, and in different packaging materials are presented in Figure 2. A significant increase ($p < 0.05$) in this parameter was observed in all oil samples throughout the storage period. However, this increase was significantly slower ($p < 0.05$) under ambient conditions compared to sunlight. This can be explained by the formation and accumulation of 2-alkenals and 2,4-dienals in these oils over storage times. The high p-anisidine value observed in oils stored under sunlight can be attributed to the fast decomposition of hydroperoxides into secondary oxidation products. Since the concentration of hydroperoxides was significantly higher compared to those under ambient condition, their decomposition rate would be higher under sunlight due to UV radiation. These results are consistent with those of Djikeng *et al.* (2019), who demonstrated that a significant increase in the p-anisidine value of palm olein when exposed to sunlight compared to ambient storage. Results also indicated that the tested oil samples displayed less secondary oxidation under sunlight when stored in BDGB and NTPB. This can be attributed to the restricted access of solar radiation into the oil in these packaging materials compared to TPEB.

These results, however, do not fully align with the finding of Grujic *et al.* (2014), who reported no significant difference in the p-anisidine value of sunflower oil during six months of storage under artificial light in clear uncolored polyethylene bottles. However, there are consolidated by the result of Kishimoto (2017), who reported that bottles with different levels of transparency offered differential protection to extra virgin oil quality during storage under sunlight, with less transparent packaging providing superior protection.

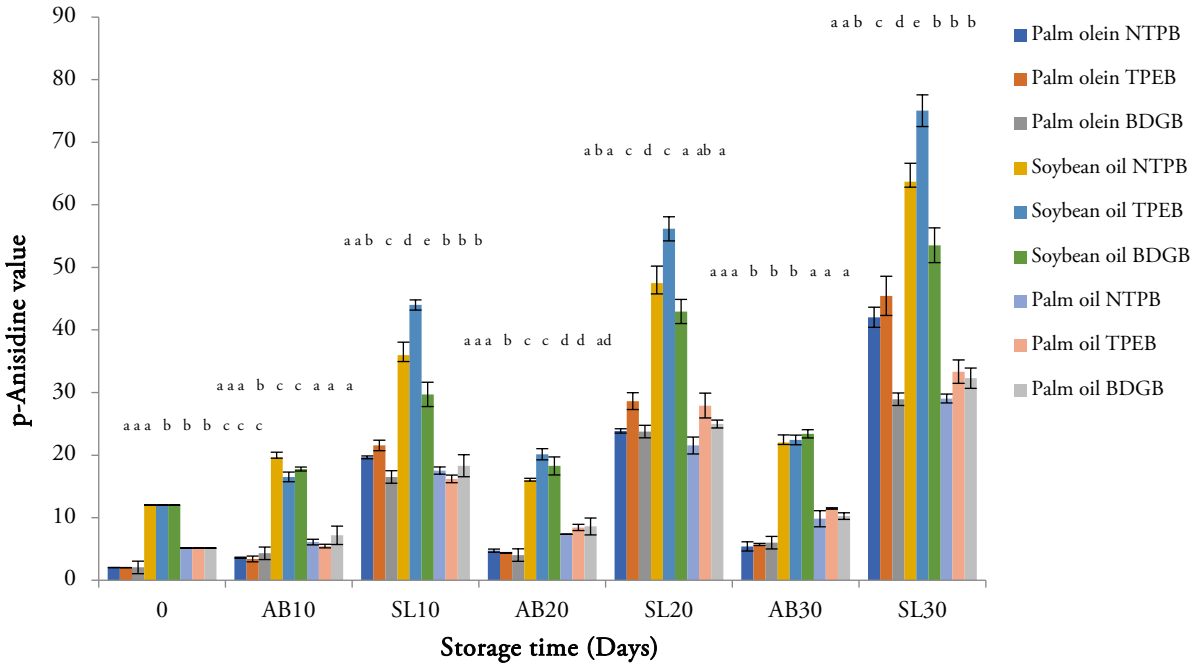

Figure 2. Changes in *p*-anisidine value of oil samples during storage. TPEB: Translucent polyethylene bottle; NTPB: Non translucent polyethylene bottle; BDGB: Brown dark glass bottles.

Note: n=3. Data are presented as mean (±SD). [a-c]Values of the same storage day and conditions with different superscripts are significantly different at p<0.05

3.1.4 TOTOX value

The determination of the TOTOX value of oils and fats provides a comprehensive assessment of their overall oxidative state, as its calculation integrates both the peroxide and p-anisidine values (Shahidi & Wanasundara, 2008). Figure 3 presents the changes in the TOTOX value of oil samples during storage under ambient and sunlight conditions, and in different packaging materials. A significant increase ($p < 0.05$) in this parameter was observed across all oil samples throughout the storage period, with this increase being more pronounced in samples exposed to direct sunlight.

Analysis of the results further indicated that the TOTOX values of oils packaged in BDGB and NTPB and exposed to sunlight were significantly ($p < 0.05$) lower than those of identical oils packaged in TPEB and subjected to similar conditions. The protective effect of NTPB and BDGB can be attributed to their ability to limit the penetration of sunlight into the oil.

These findings align with Huyan *et al.* (2019), who demonstrated that ceramic, glass, and metal packaging materials differentially influence the oxidative stability of oils. They are also consistent with the finding of Kishimoto

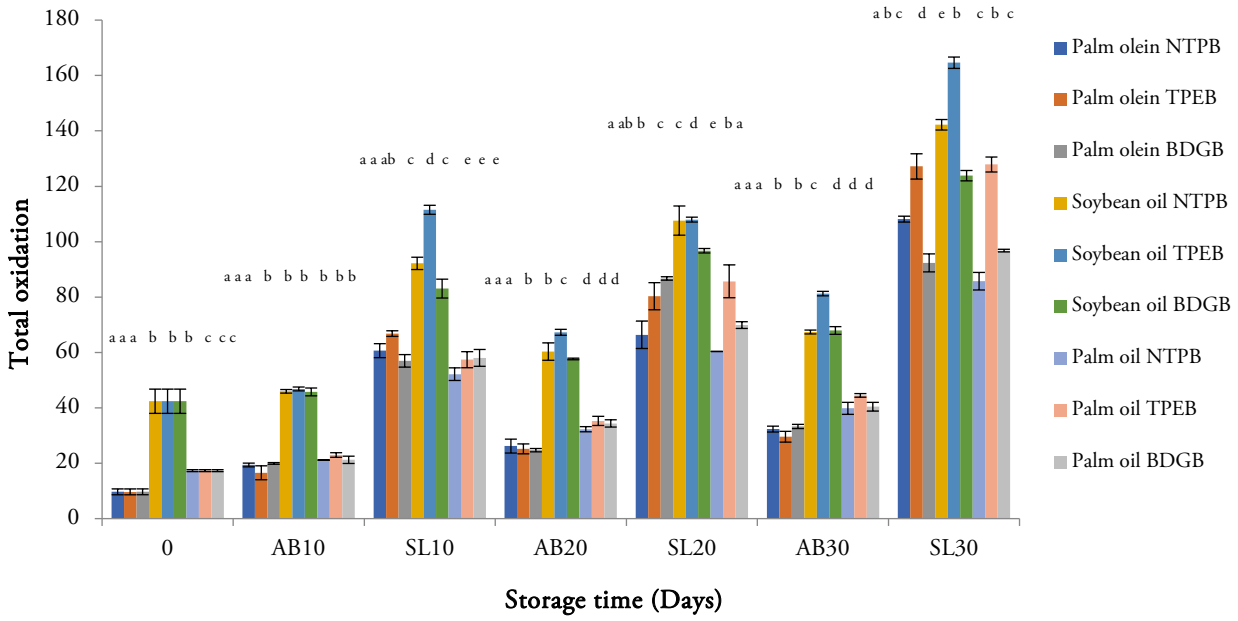

Figure 3. Changes in TOTOX value of oil samples during storage. TPEB: Translucent polyethylene bottle; NTPB: Non translucent polyethylene bottle; BDGB: Brown dark glass bottles

Note: n=3. Data are presented as mean (±SD). [a-e] Values of the same storage day and conditions with different superscripts are significantly different at p < 0.05.

This demonstrates that the oxidative activities, as evidenced by the formation and accumulation of both primary and secondary products, were more accelerated under direct sunlight compared to ambient conditions. This phenomenon can be attributed to the deleterious effects of solar radiations on oils through photooxidation reactions. Conversely, autooxidation reaction proceed at a slower step, leading to delayed alterations under ambient conditions. These findings are in line with those of Djikeng *et al.* (2019), who reported that the TOTOX value of palm olein stored under sunlight for 90 days was significantly higher than that of the same oil stored under ambient conditions.

(2019), who reported that low-transparent packaging materials offer superior protection to extra virgin oil compared to transparent ones when exposed to sunlight. However, these results exhibit only slight accordance with the those of Grujic *et al.* (2014), who observed minimal variations in the TOTOX value of sunflower oil packaged in clear uncolored glass polyethylene bottles exposed to artificial light for six months.

3.1.5 Thiobarbituric Acid (TBA) Value

The determination of the thiobarbituric acid (TBA) value serves as a measure of secondary oxidation products, which are recognized contributors to off-flavors in oxidized oils and fats (Iqbal and Bhanger, 2007). Figure 4 illustrates the

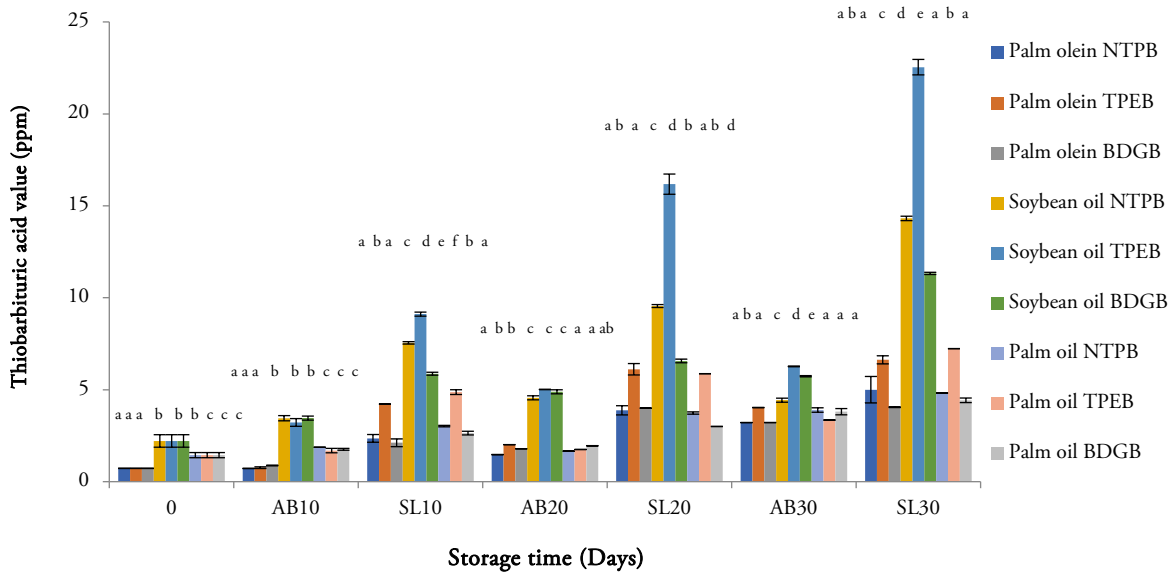

Figure 4. Changes in TBA value of oil samples during storage. TPEB: Translucent polyethylene bottle; NTPB: Non translucent polyethylene bottle; BDGB: Brown dark glass bottles

Note: n=3. Data are presented as mean (±SD). [a-e] Values of the same storage day and conditions with different superscripts are significantly different at $p < 0.05$

variations in the TBA value of oil samples during storage in various packaging materials. A significant increase ($p < 0.05$) in this parameter was recorded across all oil samples, with a more pronounced elevation observed in oils exposed to sunlight. The observed increase in TBA value can be attributed to the formation of shorter chain, dienals and malonaldehydes, which are decomposition products of hydroperoxide (Guillén-Sans & Guzmán-Chozas, 1998). The significantly higher TBA value noted in oils exposed to sunlight are likely a consequence of photooxidation reactions as sunlight appears to facilitate the decomposition of the hydroperoxides formed. Conversely, the lower TBA values observed in oils stored under ambient conditions may result from autooxidation reactions, which are slower and less destructive than photooxidation processes. These results are consistent with those obtained by Djikeng *et al.* (2019), who obtained similar trends in TBA value for palm olein, demonstrating higher values under sunlight compared to ambient conditions. Results further indicated that oils packaged in TPEB underwent greater alteration under sunlight compared to those in NTPB and BDGB. These results are in accordance with Guillén-Sans & Guzmán-Chozas, (1998), who observed higher TBA values in sunflower seed oil packaged in colorless glass bottles compared to the same oil packaged in plastic and brown glass containers. Similar observations were also reported by Ramezani (2004) for refined sunflower oil packaged in yellow polyethylene bottles, high-density polyethylene containers, and metal cans during storage in cartons as secondary packaging material.

3.1.6 Acid Value

The acid value measures the hydrolysis rate of triglyceride which is promoted by moisture and high temperature and lead to free fatty acids accumulation in oil (Freja *et al.,* 1999). The changes in acid value are exhibited in Figure 5. A statistically significant increase ($p < 0.05$) in acid value was generally observed across all oil samples throughout the storage period, relative to baseline (day zero). This phenomenon can be attributed to the breakdown of triglycerides into free fatty acid. The trend in acid value remained largely consistent under both ambient and sunlight storage conditions, with the highest acidity recorded for palm oil. This elevated acidity in palm oil may be explained by its traditional manufacturing process of palm oil which often involves high temperature and moisture, with certain parameters potentially lacking precise control. Generally, the effect of packaging materials and sunlight was not observed at this level. The fluctuation in acid value (either increase or decrease) provides an indication of oil quality; a decrease typically results from the further breakdown of formed free fatty acids into other products. These findings are not consistent with Djikeng *et al.,* (2019) who reported that sunlight significantly increase the acid value of palm olein. However, they align with Iskander *et al.* (2011), who found no significant difference in acid value of sunflower oil

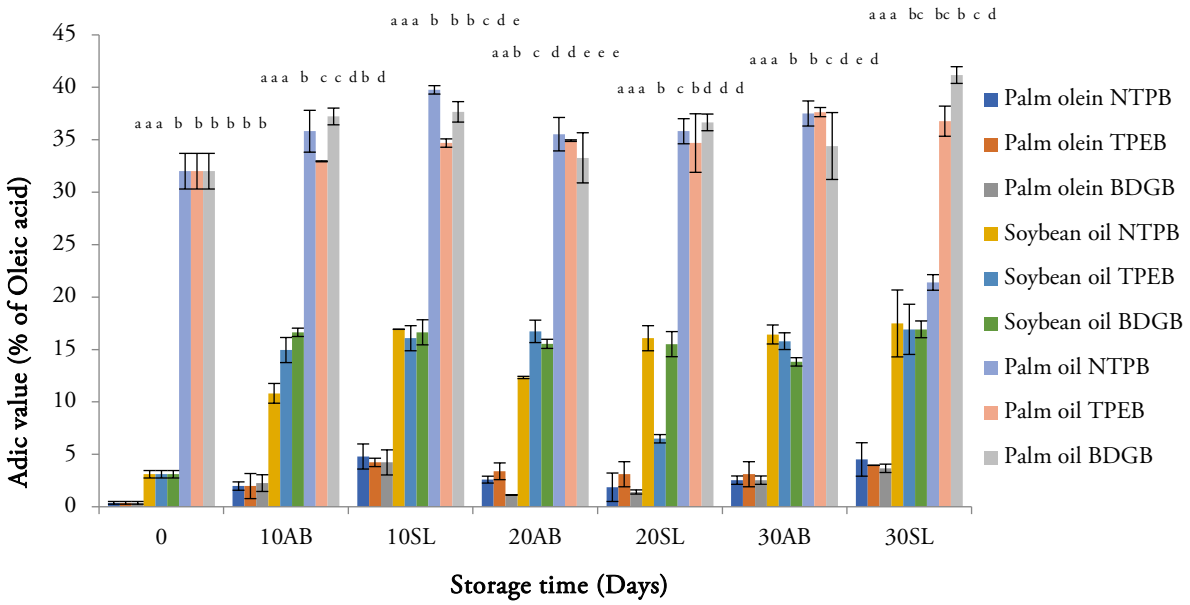

Figure 5. Changes in acid value of oil samples during storage. TPEB: Translucent polyethylene bottle; NTPB: Non translucent polyethylene bottle; BDGB: Brown dark glass bottles

Note: n=3. Data are presented as mean (±SD). [a-e] Values of the same storage day and conditions with different superscripts are significantly different at p < 0.05

packaged in plastic, colorless glass, and brown glass containers during storage under ambient conditions.

3.2 Fourier transformed-infrared spectroscopy (FTIR)

Table 2 presents the FTIR spectra of palm olein, palm oil, and soybean oil, both prior to and following storage in various packaging materials. FTIR analysis of oils provides insights into their quality through the identification of specific functional groups. Results indicated the presence of a higher number of peaks, albeit with very low intensity, in the 3250–3750 cm^{-1} region for soybean oil samples compared to the other oils. This wavenumber range is characteristic of alcohols, water, carboxylic acids, and hydroperoxides (Poiana *et al.,* 2015). A peak observed in soybean oil at 1600 cm^{-1} (intensity = 0.025), which was absent in palm oil and palm olein, corresponds to the C=O stretching of free fatty acids.

Additionally, characteristic peaks were identified at approximately 3007 cm^{-1}, 2920 cm^{-1}, 2850 cm^{-1}, 1740 cm^{-1}, 1600 cm^{-1}, 1450 cm^{-1}, 1150 cm^{-1}, and 720 cm^{-1}. The peak at approximately 3007 cm^{-1} is characteristic of the *cis* (=C–H) stretching and exhibited a higher intensity in soybean oil (intensity = 0.07). The peak observed at approximately 2920 cm^{-1} corresponds to the asymmetric C–H stretching of aliphatic groups, while the peak at 2850 cm^{-1} is attributed to the symmetric C–H stretching of aliphatic groups (Mekonnen, 2023). The peak at 1740 cm^{-1} represents the C=O stretching of esters and ketones, and its intensity was lower in soybean samples. This observation suggests elevated hydrolytic activity in soybean, leading to a reduction in the intensity of the C=O stretching characteristic of esters within the triglyceride structure. The peak identified at 1600 cm^{-1} corresponds to the *cis* -C=C- stretching of alkenes, exhibiting a higher intensity in soybean oil samples (intensity = 0.025) compared to the other samples. This can be attributed to soybean oil's high content of PUFA (Maszewska *et al.,* 2018). The peak at 1450 cm^{-1} signifies the C–H bending vibration of methylene groups in alkanes. The peak at 1150 cm^{-1} corresponds to the asymmetric C–O stretching in C–C(=O)–O ester bonds, which remained more prominent in palm oil and palm olein compared to soybean oil, consistent with the aforementioned observations concerning the C=O stretching of esters and ketones. The peak recorded at 720 cm^{-1} corresponds to the C–H rocking-bending vibration of alkanes (Mekonen, 2023).

Overall, soybean oil demonstrated the most significant alterations in quality, as evidenced by both the quality indices and the presence of specific functional groups. This can be attributed to soybean oil's high content of PUFA, which explains the observed differences. Previous studies have consistently reported that oils rich in PUFA exhibit lower stability and are more susceptible to oxidation compared to those rich in mono- or saturated fatty acids (Maszewska *et al.,* 2018).

Table 2. Shift absorption peak at between 500–3750 cm^{-1} of oil samples before and after storage

Storage period	Oil samples	Type of vibration (Mekonnen, 2023)	Functional groups (Mekonnen, 2023)	Wavenumber (cm^{-1})	Intensity
Day 0	Palm oil	OH Stretching	Alcohols, Water, Hydroperoxides, carboxylic acids	~3500	0.005
	Palm olein				0
	Soybean oil				0.02
After 30 days storage	Palm oil NTPB				0
	Palm olein NTPB				0
	Soybean oil NTPB				0.02
	Palm oil TPEB				0
	Palm olein TPEB				0
	Soybean oil TPEB				0.02
	Palm oil BDGB				0.01
	Palm olein BDGB				0.01
	Soybean oil BDGB				0.02
Day 0	Palm oil	(=C–H) stretching	Aromatics	~3006	0.025
	Palm olein				0.025
	Soybean oil				0.07
After 30 days storage	Palm oil NTPB				0.025
	Palm olein NTPB				0.025
	Soybean oil NTPB				0.07
	Palm oil TPEB				0.025
	Palm olein TPEB				0.025
	Soybean oil TPEB				0.07
	Palm oil BDGB				0.025
	Palm olein BDGB				0.025
	Soybean oil BDGB				0.07
Day 0	Palm oil	(C–H) Asymmetric Stretching	Aliphatics	~2920	0.28
	Palm olein				0.28
	Soybean oil				0.19
After 30 days storage	Palm oil NTPB				0.28
	Palm olein NTPB				0.28
	Soybean oil NTPB				0.19
	Palm oil TPEB				0.28
	Palm olein TPEB				0.28
	Soybean oil TPEB				0.195
	Palm oil BDGB				0.28
	Palm olein BDGB				0.28
	Soybean oil BDGB				0.19
Day 0	Palm oil	(C–H) Symmetric Stretching	Aliphatics	~2850	0.195
	Palm olein				0.195
	Soybean oil				0.135
After 30 days storage	Palm oil NTPB				0.195
	Palm olein NTPB				0.195
	Soybean oil NTPB				0.135
	Palm oil TPEB				0.195
	Palm olein TPEB				0.195
	Soybean oil TPEB				0.135
	Palm oil BDGB				0.195
	Palm olein BDGB				0.195
	Soybean oil BDGB				0.135

Table 2. (Continued)

Day 0	Palm oil	(C=O) stretching	Esters and ketones	~1740	0.26
	Palm olein				0.25
	Soybean oil				0.13
After 30 days storage	Palm oil NTPB				0.26
	Palm olein NTPB				0.25
	Soybean oil NTPB				0.125
	Palm oil TPEB				0.26
	Palm olein TPEB				0.25
	Soybean oil TPEB				0.135
	Palm oil BDGB				0.26
	Palm olein BDGB				0.25
	Soybean oil BDGB				0.14
Day 0	Palm oil	(C=C-) *Cis* Stretching	Alkenes	~1600	0
	Palm olein				0
	Soybean oil				0.025
After 30 days storage	Palm oil NTPB				0
	Palm olein NTPB				0
	Soybean oil NTPB				0.025
	Palm oil TPEB				0
	Palm olein TPEB				0
	Soybean oil TPEB				0.025
	Palm oil BDGB				0
	Palm olein BDGB				0
	Soybean oil BDGB				0.025
Day 0	Palm oil	(C–H) bending vibration in methylene	Alkanes	~1450	0.09
	Palm olein				0.09
	Soybean oil				0.085
After 30 days storage	Palm oil NTPB				0.09
	Palm olein NTPB				0.09
	Soybean oil NTPB				0.07
	Palm oil TPEB				0.09
	Palm olein TPEB				0.09
	Soybean oil TPEB				0.07
	Palm oil BDGB				0.09
	Palm olein BDGB				0.09
	Soybean oil BDGB				0.08
Day 0	Palm oil NTPB	Asymmetric C–O Stretching in C–C(=O)–O bonds	Esters	1150	0.17
	Palm olein NTPB				0.175
	Soybean oil NTPB				0.12
After 30 days storage	Palm oil NTPB				0.175
	Palm olein NTPB				0.175
	Soybean oil NTPB				0.11
	Palm oil TPEB				0.175
	Palm olein TPEB				0.175
	Soybean oil TPEB				0.11
	Palm oil BDGB				0.175
	Palm olein BDGB				0.175
	Soybean oil BDGB				0.11
Day 0	Palm oil	C–H rocking-bending vibration	Alkanes	~720	0.08
	Palm olein				0.08
	Soybean oil				0.18
After 30 days storage	Palm oil NTPB				0.08
	Palm olein NTPB				0.08
	Soybean oil NTPB				0.17
	Palm oil TPEB				0.08
	Palm olein TPEB				0.08
	Soybean oil TPEB				0.17
	Palm oil BDGB				0.08
	Palm olein BDGB				0.08
	Soybean oil BDGB				0.17

4 Conclusion

In Cameroon, palm oil, palm olein, and soybean oil, being the most produced and consumed, are typically packaged in both translucent and opaque polyethylene bottles for commercial distribution. These oils are frequently retailed in local markets where they are routinely exposed to direct solar radiation for promotional purposes until sale. This exposure can accelerate photooxidation and subsequently diminish their quality. Consequently, this study was carried out to assess the behavior of these oils when stored in various packaging materials under both direct sunlight and dark ambient conditions, and to propose optimal packaging solutions for quality preservation.

The findings revealed that solar radiation significantly compromises the quality of these oils compared to storage under dark ambient conditions. Soybean oil exhibited a more rapid oxidation rate than the other oils under both storage conditions. Oil samples stored in NTPB and BDGB demonstrated reduced photooxidative degradation, thereby identifying them as adequate packaging materials for these products. It is therefore recommended that future investigations should focus on the endogenous antioxidants and vitamin content of the oils, and the effect of solar radiations on the integrity of polyethylene packaging materials.

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