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Research Article

Preservative Effect of Ginger Root (*Zingiber officinale* R.) Extract in Refined Palm Olein Subjected to Accelerated Thermal Oxidation

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Oils and fats are susceptible to the oxidation of their unsaturated fatty acids during processing, storage, or handling. Oxidation reactions lead to serious damages to oil quality that makes it to be rejected by consumers for health issues and industries that might undergo financial challenges. To limit these damages, chemically synthesized antioxidants have been added to oils and fats as preservatives. However, these were reported not to be healthy and natural substitutes extracted from plant have been the main focus of many researchers and industries these recent years. This study aimed at evaluating the preservative effect of ginger root extracts in inhibiting palm olein alteration during accelerated air-dried oven storage at 180°C. The natural antioxidants were added to palm olein at the concentrations of 200, 600, 1000, 1400, and 1800 ppm and kept in the air-dried oven for six days at 180°C (daily heating was 4 h). Butylated hydroxytoluene (BHT) was used as positive control and oil with no additive functioned as the negative one. Oil samples were collected from the oven after every 2 days for analysis. The quality parameters including the peroxide value (PV), the *p*-anisidine value (*p*-AV), the total oxidation value (TOTOX), the acid value (AV), the thiobarbituric acid value (TBA), and the iodine value (IV) were determined. The changes in the fatty acid composition of palm olein were characterized by gas chromatography coupled to a flame ionization detector (GC/FID). The ginger extract was found to be effective in delaying palm olein alteration during processing. Extract efficiency was concentration-dependent and was better than that of the control and the sample supplemented with butylated hydroxytoluene (BHT). Therefore, ginger root extract can be an ideal alternative to synthetic antioxidants used in palm olein.

1. Introduction

Frying is a famous practice in food manufacturing. It is a very short process, which takes about 05–10 minutes and generally involves very high temperatures [1]. This cooking process is rapid, suitable, and energy-efficient. It raises the nutritional and organoleptic properties of foods due to fat holding, development of agreeable savors, and aromas [1]. However, throughout this practice, high temperatures can promote physical and chemical modifications in the oil that can enable its oxidation when moisture and oxygen are available. The chemical alteration reactions that generally occur in oil during frying include hydrolysis, thermoxidation, polymerization, and isomerization. These chemical reactions downgrade both the quality of the oil and the fried products [2]. Oxidation reactions generally reduce the

quality attributes of oil and fried goods by decreasing their nutritional properties (destruction of essential fatty acids, essential amino acids, vitamins, and reduction in protein digestibility) [3]. These reactions also alter the sensory characteristics of foods by modifying their color, texture, and appearance and by leading to the formation of undesirable flavors and odors. Additionally, during frying, some toxic compounds (aldehydes, ketones, free radicals, reactive oxygen species, polymers, and many more) can be generated. These are well known to be toxic for humans as they are associated with several health disorders such as cancer, Parkinson's disease, and cardiovascular disease [4]. The degree of spoilage of oil during frying relies on factors such as temperature, frying time, type of food, frying method, and fatty acid and phytochemical composition of the fat or oil [5].

To neutralize free radicals, synthetic antioxidants have been added to oil at their recommended concentrations with the objective to stop the formation of poisonous substances released during the secondary oxidation stage of fatty acids. Examples of synthetic antioxidants used include butylated hydroxyanisole, butylated hydroxytoluene, and *tert*-butylhydroquinone [6]. However, chemically synthesized preservatives are strictly controlled and prohibited in some countries as the consumer's awareness towards them is also growing. Nowadays, consumers prefer natural products or food containing natural preservatives as they are considered to be safer [4]. In addition, some of these preservative agents have been demonstrated to have poor stability at high temperatures as they are easily decomposed under such conditions [7–9]. Due to this safety concern, there is a growing attention in food and medicinal factories to substitute chemically produced preservatives with natural ones [10].

The fact that plants are good sources of antioxidants is already well known. Among them, spices and herbs are more interesting, since these contain several antioxidants among which vitamins, carotenoids, phenolic acids, flavonoids, and tannins which give them the property to be interesting preservative agents in food.

Zingiber officinale, also known as ginger, fits in the Zingiberaceae family and has been used as spice in the preparation of food, as well as in traditional medicine because of its pharmacological properties [11]. In the Chinese and Indian traditional medicines, ginger roots have been served in the handling of wild range of health problems such as nausea, respiratory problems, asthma, and stomachache [12]. Previous reports showed that some molecules or substances present in ginger roots such as gingerol, shogaol, diarylheptanoids, and essential oil components are efficient in preventing disorders such as carcinogenesis, diabetes, oxidative stress, and inflammatory [13, 14].

Several studies have demonstrated that ginger root extract is rich in phenolic antioxidants (such as 6-gingerol and its products), which are very good free radical scavengers [13, 14]. Though ginger extract is an interesting reservoir of naturally occurring antioxidant, relatively limited reports are available on the evaluation of their ability to lengthen the shelf life of oils. In one report, Djikeng et al. [14] demonstrated that the methanolic extract of ginger roots contains gingerol and ferulic acid and was efficient in delaying palm olein alteration under forced storage conditions (30 days of storage at 70°C). However, the ability of this extract in inhibiting fat oxidation under frying conditions has not yet been described. Fabrice et al. [15, 16] demonstrated that the methanolic extract of *Camellia sinensis* leaves and *Annona muricata* flowers was efficient in retarding palm olein adulteration during 6 days of storage in an oven at frying temperatures (180°C). Due to the fact that palm olein is highly solicited in the world for frying purposes, it will be quite interesting to have an idea about the ability of ginger root extract in prolonging its shelf life. Ginger root methanolic extract might be rich in antioxidative substances with good thermal resistance that can limit oxidative damages in palm olein during frying.

This study was conducted to explore the ability of different concentrations of *Zingiber officinale* root extract in slowing down palm olein alteration during processing at high temperature.

2. Materials and Methods

2.1. Materials. Additive-free palm olein was purchased from SCS/RAFCA, located in Bafoussam, west region of Cameroon. The fresh ginger roots were bought from a farm in Santchou, west region of Cameroon directly after harvesting. Santchou is a town located in the Menoua division of the west region of Cameroon. It is located between 5°10′ and 5°20′ altitude north and 10°20′ and 10°21′ longitude east. It is limited in north by the Dschang subdivision, south by the Melong subdivision, west by the Bandja subdivision, and east by the Nguti subdivision. The climate is hot and humid, Cameronian type with a pseudo-tropical rainfall regime. The mean average annual temperature is 23°C with a rainfall index of 1662.7 mm per year for 156 rainy days.

All chemicals and reagents used were of analytical grade. Methyl esters of fatty acids were purchased from Sigma-Aldrich, St. Louis, USA. The other chemicals were, respectively, purchased from S.D. Fine Chemical, HiMedia Laboratories Pvt., Mumbai, India, and Sigma-Aldrich, St. Louis, USA.

2.2. Methods

2.2.1. Bioactive Extraction from Ginger Roots. The fresh ginger roots were taken to the laboratory where, after cleaning, they were reduced to small pieces using a knife and oven-dried at 50°C for exactly 48 h. The dehydrated roots were reduced to powder and sieved using a 1 mm diameter sieve. About 200 g of sieved ginger was extracted with 800 ml of methanol using the maceration method. Samples were stirred during the extraction in view to optimize the extraction of phenolic compounds. After separation using the Whatman paper No. 1, the similar process was again repeated with ginger residues obtained from the previous extraction, but this time used 400 mL of solvent to make sure that the majority of the phenolic compounds were extracted. Upon filtration, both filtrates were mixed and vaporized

under vacuum at 40°C using a rotatory evaporator. The dried extract was kept in the fridge at 4°C for analysis.

2.2.2. Sample Preparation. The method reported by Iqbal et al. [17] served the preparation of the samples. Ginger extract at the concentrations of 200, 600, 1000, 1400, and 1800 mg/kg or ppm was, respectively, supplemented with preheated refined palm olein, after the extract was dissolved with a small volume of methanol (1 ml). Oil without antioxidant was used as the negative control and received only 1 ml of methanol, while the BHT at its accepted concentration (200 ppm) as per the norm [18] was also dissolved in 1 ml of methanol served as positive control. The amount of methanol added to oil was 1 mL/100 g, which is in line with the norm, since it was lower than the homologated concentrations (10 mg/kg in Europe and 50 mg/kg in Japan) to be added in one kilogram of oil or food samples [19–21]. It should also be known that after stirring oil samples containing the methanolic solutions, they were kept in the oven for 48 h at 45°C to further reduce the concentration of methanol. Samples were prepared in triplicate. After this, the Schaal oven test was performed.

2.2.3. Oven Test. The technique was used by Sultana et al. [22] served to perform the Schaal oven test with minor adjustments. All oil samples were introduced in an electric air-dried oven and consecutively heated for six days at 180°C (4 h heating per day). After every two days, oil samples were collected and kept in the fridge for further analysis. Products from primary and secondary oxidation reactions were characterized, same with the impact of storage on the fatty acid composition of oil samples.

2.2.4. Quality Analysis of Oil Samples. The oxidative factors evaluated on each oil sample comprised the peroxide value, determined using the IDF standard method 74A: 1991 [23], the *p*-anisidine and acid values assessed using the AOCS method CD 18–90 and CD 1–15 [24], the thiobarbituric acid (TBA) value, determined using the method reported by Draper and Hadley [25], the iodine value characterized using the AOCS method CD 1–25 [24], and the TOTOX value obtained by calculation from the peroxide and *p*-anisidine values as follows: TOTOX = 2PV + *p*-AV [26].

2.2.5. Variations in Fatty Acid Composition of Palm Olein during Accelerated Storage

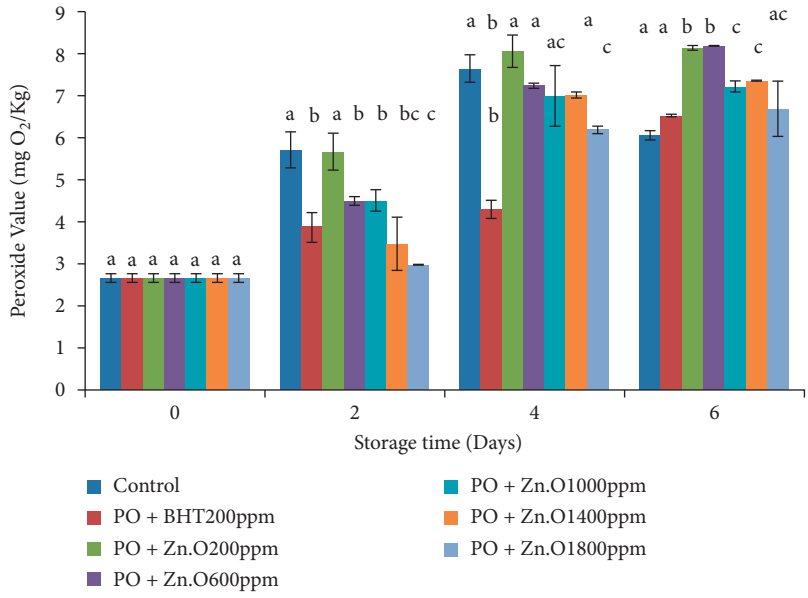
(1) Fatty Acid Methyl Ester (FAME) Preparation. The FAMEs of all oil samples were obtained by transesterification using a 2% methanolic solution of sulfuric acid [27]. The FAMEs were extracted using ethyl acetate and washed with tap water to discard the acid. After that, the samples were dried using sodium sulphate (anhydrous). The dried esters were scrutinized in a gas chromatograph coupled with a flame ionization detector (GC/FID).

(2) Gas Chromatography Analysis. A gas chromatograph (Agilent Technologies, Palo Alto, CA, USA, No. of series 7890A) coupled to a flame ionization detector (FID) and a capillary column DB-225 (30 m × 0.25 μm of film width) was served to analyze the FAMEs. In the beginning, the temperature in the column was maintained for the duration of 2 min at 160°C. After that, it rose to 220°C (5°C/min) and was stabilized at 220°C for about 10 min. The mobile phase used in this analysis was nitrogen (debit: 1.5 ml/min). The injector and detector exhibited temperature values of 250 and 230°C. The FAMEs were recognized by comparing their holding times to those of standard FAMEs characterized under similar circumstances.

2.2.6. Statistical Analysis. One-way analysis of variance (ANOVA) was used to analyze the data. The Student–Newman–Keuls test was used to appraise the statistical significance of the data using the software GraphPad InStat version 3.05. The variances were significant at $p < 0.05$.

3. Results and Discussion

3.1. Peroxide Value (PV). The assessment of the PV of oils informs on the amount of hydroperoxides formed during the primary oxidation stage. Hydroperoxides can further break down into unstable and stable secondary oxidation products, which reduce the sensorial and nutritional quality of the fat [28, 29]. In this work, the variations in PV of palm olein enriched with natural and synthetic antioxidants and the one of the controls are presented in Figure 1. In general, the PV of all samples supplemented with antioxidants was meaningfully increasing ($p < 0.05$) with storage time. Similar observations were shown for the control during the first four days. However, from day 4 forward, its value significantly decreased ($p < 0.05$). The PV of PO + BHT_{200ppm} was considerably lower ($p < 0.05$) than that of oil samples containing ginger extract as preservative during the entire storage. The rise in PV recorded in all samples indicates the development of hydroperoxides. When oils are heated at high temperature, the hydrogen atoms carried by the methylene group between two double bonds or before or after a double bond can be abstracted, therefore promoting the formation of alkyl radicals. These free radicals can be involved in a reaction with triplet oxygen molecules and lead to the formation of peroxy compounds, which are very reactive. The new radicals being unstable can remove another hydrogen molecule from a neighboring molecule, which can be a fatty acid to produce hydroperoxides [30]. The important reduction in PV registered with the control from the fourth day can be attributed to the decomposition of hydroperoxides into volatile and nonvolatile compounds, which are secondary oxidation products [31]. The relative increase in PV of oils supplemented with antioxidant during the storage might be related to their low oxidation state compared with the control. This activity can be related to the presence of antioxidants. It is, however, important to note that the PV is not a suitable test for quality evaluation oils subjected to high temperatures, as they easily break down into other molecules

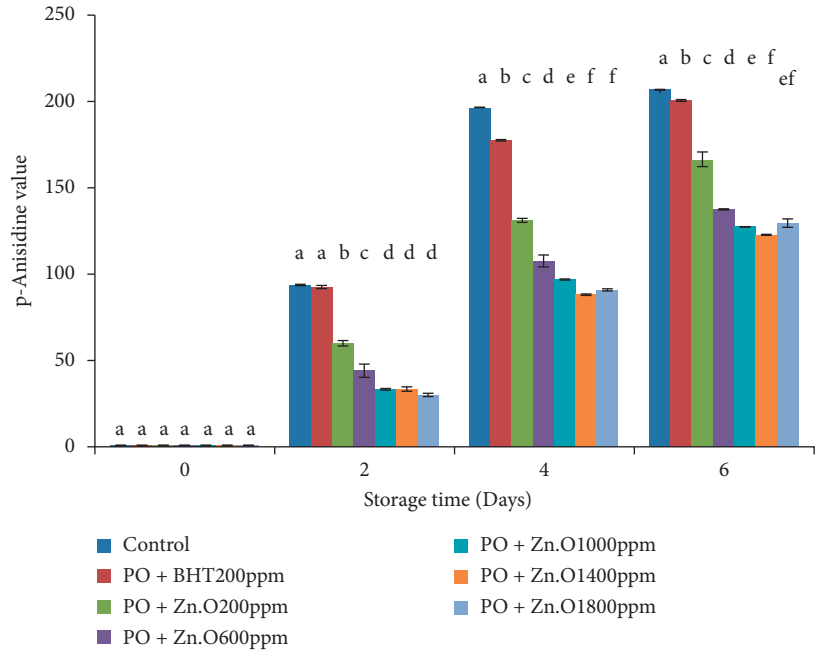


Data are presented as Mean ± Standard deviation (n = 3). [a-c]Values of the same storage day with different superscripts differ considerably at $p<0.05$

FIGURE 1: Changes in peroxide value of palm olein enriched with different concentrations of ginger extract throughout a storage at frying temperature. BHT: butylated hydroxytoluene; PO: palm olein; Zn.O: *Zingiber officinale* (ginger); control: palm olein without antioxidant; PO + $BHT_{200\ ppm}$: palm olein + 200 ppm BHT; PO + $Zn.O_{200ppm}$: palm olein + 200 ppm ginger root extract; PO + $Zn.O_{600ppm}$: palm olein + 600 ppm ginger root extract; PO + $Zn.O_{1000ppm}$: palm olein + 1000 ppm ginger root extract; PO + $Zn.O_{1400ppm}$: palm olein + 1400 ppm ginger root extract; PO + $Zn.O_{1800ppm}$: palm olein + 1800 ppm ginger root extract. Data are presented as mean ± standard deviation ($n = 3$). [a–d]values of the same storage day with different superscripts are significantly different at $p < 0.05$. Data are presented as mean ± standard deviation ($n = 3$). [a–c]values of the same storage day with different superscripts differ considerably at $p < 0.05$.

called secondary oxidation products. This parameter is useful under such conditions if and only if secondary oxidation products are also characterized to find whether or not they were converted into volatile and nonvolatile compounds [16]. It is therefore impossible to conclude that the extracts and BHT really preserved the oil under these conditions since low PV can be associated with oil quality whether it is bad or good. Also, high temperatures can impact the activity of some antioxidants, leading to the loss of their function [7]. Djikeng et al. [14] reported that ginger extracts at the concentrations of 200–1800 ppm preserve the quality of palm olein at a similar level to the BHT throughout 30 days of storage at the temperature of 70°C. Similar data were also reported by Che Man and Tan [32], who showed that sage and rosemary extracts are effective preservatives in palm olein during the frying of potato chips.

3.2. p-Anisidine Value (AnV). This parameter measures the products of hydroperoxide decomposition, especially aldehydes, carbonyl, ketones, etc. This is the phase leading to oil rancidity [33]. The fluctuations in AnV of palm olein samples during 6 days of storage at 180°C are illustrated in Figure 2. A relative rise ($p < 0.05$) in AnV was detected in all oil samples. The highest *p*-anisidine values were registered with the control and PO + BHT_{200ppm}, which displayed expressively higher ($p < 0.05$) *p*-anisidine values equaled to oil models enriched with ginger extract. The effectiveness of the extract was concentration-dependent. The rise in AnV value recorded in all models can be attributed to the formation of 2-alkenals and 2, 4-dienals, which are decomposition products of hydroperoxides. The high *p*-anisidine values recorded with the control and the oil fortified with BHT at the concentration of 200 ppm compared with other samples are the evidence of their high secondary alteration. This can be explained by the nonexistence of antioxidants in the control [15] and the volatility of BHT at elevated temperature in PO + BHT_{200ppm} as reported by Chang et al. [7] and Djikeng et al. [14]. The antioxidants in ginger root methanolic extract might have better thermal stability and antioxidant activity than the BHT. Djikeng et al. [14] demonstrated that the methanolic extract of ginger is rich in phenolic compounds (34.63 mg GAE/g). They also noticed the occurrence of ferulic acid and gingerol in that extract and showed that it has good antioxidant properties. These compounds might be responsible for the good preservative effect of palm olein during storage at 180°C. The lowest peroxide value previously registered with PO + BHT_{200ppm} was not a sign of its good stability, but the magnitude of the decomposition of its hydroperoxides into secondary oxidation products. The fact that some plant extract antioxidants have better thermal stability than synthetic antioxidants has already been reported. Chang et al. [7] and Thorat et al. [8] established that BHT and BHA easily decompose at elevated processing temperature (>140°C). In the same line, Iqbal and Bhanger [34] indicated that extracts of garlic and pomegranate have better stability than BHA at 185°C.

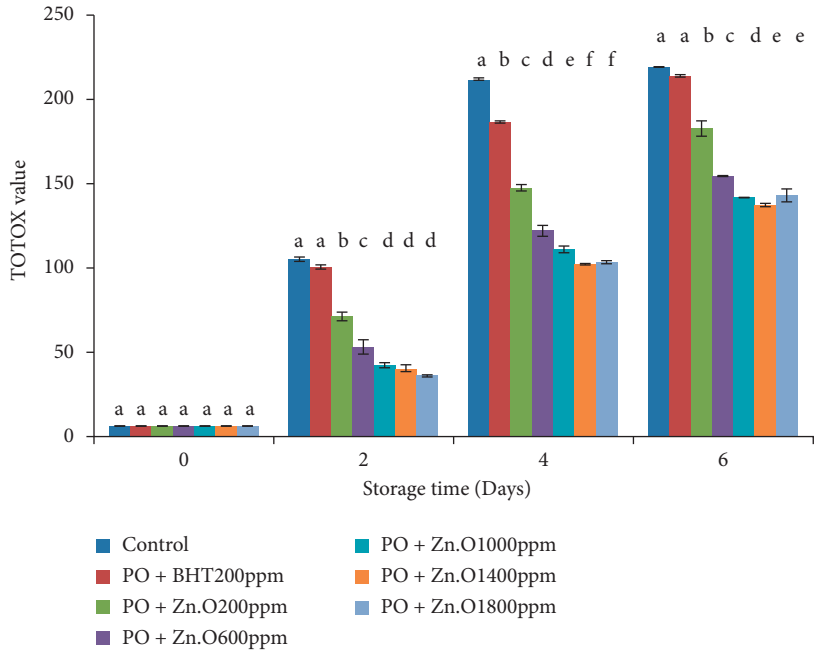


Data are presented as Mean ± Standard deviation (n = 3). [a-f]Values of the same storage day with different superscripts differ considerably at $p<0.05$

FIGURE 2: Variations in *p*-anisidine value of palm olein enriched with different concentrations of ginger extract during storage at frying temperature. BHT: butylated hydroxytoluene; PO: palm olein; Zn.O: *Zingiber officinale* (ginger); control: palm olein without antioxidant; PO + $BHT_{200\ ppm}$: palm olein + 200 ppm BHT; PO + $Zn.O_{200ppm}$: palm olein + 200 ppm ginger root extract; PO + $Zn.O_{600ppm}$: palm olein + 600 ppm ginger root extract; PO + $Zn.O_{1000ppm}$: palm olein + 1000 ppm ginger root extract; PO + $Zn.O_{1400ppm}$: palm olein + 1400 ppm ginger root extract; and PO + $Zn.O_{1800ppm}$: palm olein + 1800 ppm ginger root extract. Data are presented as mean ± standard deviation ($n = 3$). [a–f]values of the same storage day with different superscripts differ considerably at $p < 0.05$.

3.3. TOTOX Value. The variations in TOTOX value of palm olein samples are shown in Figure 3. Globally, an important rise ($p < 0.05$) in this factor was noted in all samples throughout the experiment. Palm olein supplemented with BHT (PO + BHT_{200ppm}) and control (oil without additive) was more oxidized during the entire storage period. Their TOTOX values were meaningfully elevated ($p < 0.05$) compared with those of oil samples fortified with ginger extract at different concentrations. The low TOTOX value disclosed in oil samples complemented with ginger extract might be credited to the protective effect of its natural antioxidants. Djikeng et al. [14] demonstrated that the methanolic extract of ginger is rich in phenolic compounds, among which gingerol is the most represented. Ferulic acid was also found in the extract by the same authors. The high TOTOX value of the control can be explained by the absence of antioxidants, while that of the oil complemented with the BHT at the concentration of 200 ppm can be accredited to the volatility of the BHT at high processing temperature as reported by Chang et al. [7], Thorat et al. [8], and Womeni et al. [9]. It is important to note that the antioxidant activity of the plant extract was proportional to its concentration. These outcomes are in accordance with those of Womeni et al. [9] and Djikeng et al. [14] who separately showed that the protective effect of green tea leaves and ginger root methanolic extracts in palm olein throughout 30 days of storage at 70°C was concentration-dependent.

3.4. Thiobarbituric Acid Value. This parameter has been widely exploited to measure the concentration of malondialdehyde present in oil throughout the secondary oxidation of its unsaturated fatty acids [17]. Malondialdehyde accumulation in oils during storage impacts their quality, as it is accountable for the development of off-flavors and rancid odor. The fluctuations in TBA values of palm olein enriched with antioxidants and control (oil without additive) are presented in Figure 4. An important rise ($p < 0.05$) in TBA value was observed in all models during storage. Both the control and the oil sample supplemented with BHT presented meaningfully higher ($p < 0.05$) TBA value compared with oil models supplemented with ginger extract. However, on the sixth day, the TBA value of the control was expressively higher ($p < 0.05$) than that of PO + BHT_{200ppm}. The high TBA value of control as opposed to the other oil samples can be credited to the deficiency in preservatives. On the other hand, the low TBA value of stabilized oils might be the consequence of the presence of natural antioxidants. The antioxidant action of *Zingiber officinale* root extract was better than that of BHT. This can be due to the low thermal stability of BHT compared with the phenolic antioxidants present in ginger, explicitly gingerol and ferulic acid as demonstrated by Djikeng et al. [14]. Generally, the activity of *Zingiber officinale* extract rose with its concentration. These outcomes are in line with those of Fabrice et al. [15] who reported that the methanolic extracts of tea leaves and soursop flowers at the concentrations of 200–1800 ppm

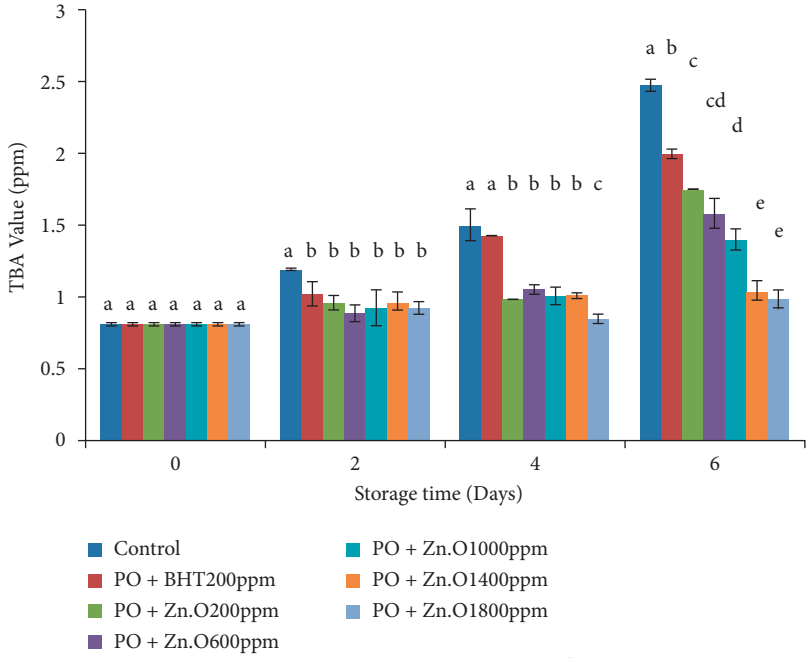


Data are presented as Mean ± Standard deviation (n = 3). [a-d]Values of the same storage day with different superscripts differ significantly at $p<0.05$

Figure 3: Variations in TOTOX value of palm olein enriched with different concentrations of ginger extract during storage at frying temperature. BHT: butylated hydroxytoluene; PO: palm olein; Zn.O: *Zingiber officinale* (ginger); control: palm olein without antioxidant; PO + $BHT_{200\ ppm}$: palm olein + 200 ppm BHT; PO + $Zn.O_{200ppm}$: palm olein + 200 ppm ginger root extract; PO + $Zn.O_{600ppm}$: palm olein + 600 ppm ginger root extract; PO + $Zn.O_{1000ppm}$: palm olein + 1000 ppm ginger root extract; PO + $Zn.O_{1400ppm}$: palm olein + 1400 ppm ginger root extract; PO + $Zn.O_{1800ppm}$: palm olein + 1800 ppm ginger root extract. Data are presented as mean ± standard deviation ($n = 3$). [a–d]values of the same storage day with different superscripts differ significantly at $p < 0.05$.

considerably delayed ($p < 0.05$) the production of malondialdehyde in palm olein throughout 6 days at 180°C. These authors also showed that extract activity was proportional to its concentration and better than that of BHT. Similar observations were reported by Che Man and Tan [32] who showed that rosemary and sage extracts were more effective in inhibiting malondialdehyde development in palm olein during the frying of potato chips than the BHA and BHT.

3.5. Iodine Value (IV). Palm olein is composed of more than 60% of fatty acids (FAs) with at least one double bond [15]. These FAs are recognized to be susceptible to oxidation reactions. During storage or thermal processing, the unsaturation present in the aliphatic chain of fatty acids can be destroyed by free radicals, resulting in the development of conjugated bonds [35]. Thus, measuring the degree of unsaturation available in palm olein can be exploited as reference to evaluate oil freshness. The fluctuations in iodine value of palm olein models during storage under simulated frying conditions are shown in Figure 5. A major decrease ($p < 0.05$) in IV was recorded in all oil models during 6 days of storage. However, the highest decrease was disclosed by the control, PO + $BHT_{200ppm,}$ and PO + $Zn.O_{200ppm}$, as these exhibited the lowest IV compared with oil samples supplemented with ginger extract at the concentration of 600–1800 ppm. This specifies that the degree of oxidation of their unsaturated fatty acids was high, probably because of the lack of antioxidant in the control, or the thermal volatility of BHT, or the low concentration of ginger extract (200 ppm). It has been demonstrated that the antioxidant potential of a substance can be affected by its concentration and processing temperature (Iqbal et al. [17]). As a consequence, oil becomes defenseless and abandoned to free radicals, which destroy their unsaturated fatty acids. The lowest change in IV of oil samples complemented with ginger extract at the concentration of 600–1800 ppm is a sign of the little demolition of their unsaturated fatty acids, owing to the aptitude of the antioxidant substances present to slow down the deteriorative influence of free radicals by giving their hydrogen atoms for their neutralization [14]. Thus, it can be stated that ginger extract at the concentration of 600–1800 ppm is effective in preserving unsaturated fatty acid double bonds from attacks by free radicals. Its activity was better than that of BHT. This can be related to the thermal resistance and good antioxidant activity of the phenolic substances existing in the plant extract used. As previously mentioned, the methanolic extract of ginger has already been proven to be rich in phenolic compounds with good antioxidant activity. Gingerol was proven to be its main antioxidant [14]. The outcomes gotten in this study displaying that ginger extract can delay the destruction of the double bonds found in the structure of unsaturated fatty acids constitutive of palm olein throughout processing at high temperature are in line with the report of Djikeng et al. [14]. These authors showed that the ginger extract at the



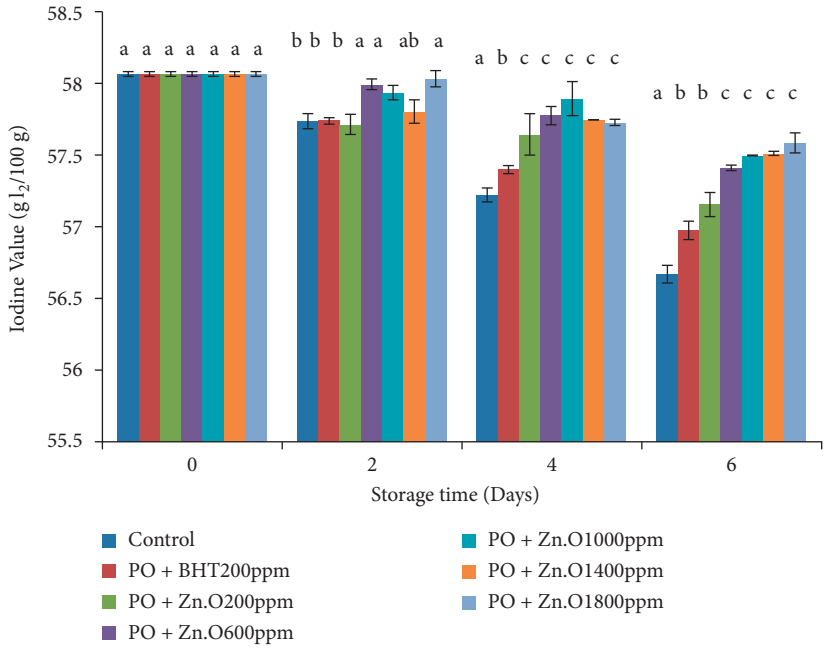
Data are presented as Mean ± Standard deviation (n = 3). [a-d]Values of the same storage day with different superscripts differ significantly at $p<0.05$

FIGURE 4: Variations in thiobarbituric acid value of palm olein enriched with different concentrations of ginger extract during storage at frying temperature. BHT: butylated hydroxytoluene; PO: palm olein; Zn.O: *Zingiber officinale* (ginger); control: palm olein without antioxidant; PO + $BHT_{200\ ppm}$: palm olein + 200 ppm BHT; PO + $Zn.O_{200ppm}$: palm olein + 200 ppm ginger root extract; PO + $Zn.O_{600ppm}$: palm olein + 600 ppm ginger root extract; PO + $Zn.O_{1000ppm}$: palm olein + 1000 ppm ginger root extract; PO + $Zn.O_{1400ppm}$: palm olein + 1400 ppm ginger root extract; PO + $Zn.O_{1800ppm}$: palm olein + 1800 ppm ginger root extract. Values with different superscripts on the same days are significantly different at $p < 0.05$. Data are presented as mean ± standard deviation ($n = 3$). [a–e]values of the same storage day with different superscripts differ significantly at $p < 0.05$.

concentration of 200–1800 ppm was able to slow down the reduction in iodine value of palm olein throughout 30 days of storage under forced conditions at the temperature of 70°C. Similar findings have also been reported by Che Man and Tan [32] with sage and oleoresin rosemary during the frying of potato chips with palm olein.

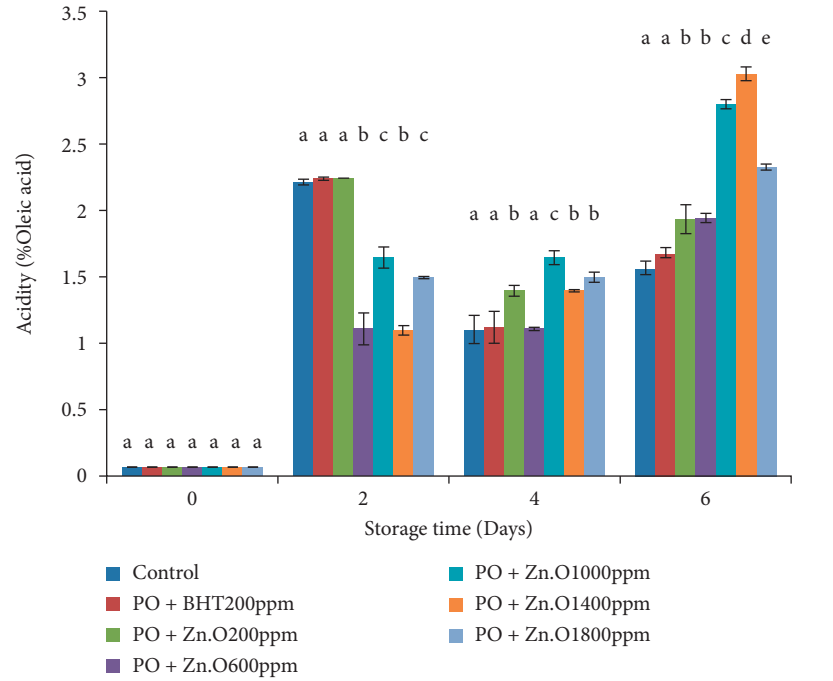
3.6. Acid Value (AV). The purpose of the AV of oil and fats is to inform on the hydrolysis rate of their triglycerides. This chemical alteration reaction is generally catalyzed or promoted by moisture and drastic processing conditions such as high temperatures. It is an important indicator of oil and fat rancidity [36]. The variations in the acid value of palm olein samples during six (06) days of subjection to frying temperature are presented in Figure 6. An important rise in this parameter was detected in all samples compared with the initial ones (day 0). The increase was constant with oil samples complemented with ginger extract at the concentration of 600–1800 ppm, while in the other samples (control, PO + $Zn.O_{200ppm,}$ and PO + BHT_{600ppm}) it significantly rose on the second day and declined on the fourth day before increasing again on the sixth day. The global rise in AV observed in all the samples can be credited to hydrolytic reactions, which gradually break down the triglycerides and release free fatty acids (FFAs). It has been demonstrated that esterified fatty acids resist better towards oxidation reactions than free fatty acids [36]. This means that oxidation reactions are promoted with the presence of free fatty acids. The significant decrease in acid value registered with the control, PO + $Zn.O_{200ppm,}$ and PO + BHT_{600ppm} can be attributed to their high oxidation rate that led to the change in free fatty acids into hydroperoxides. This is understandable because these samples were the most altered as previously demonstrated. Oil samples supplemented with the plant extract exhibited a lower hydrolysis rate. The fact that the presence of natural antioxidant can reduce the rate of hydrolysis reaction in oils and fats has already been reported [17, 34]. However, a clear mechanism of action of antioxidants in inhibiting hydrolytic reactions has not yet been reported.

3.7. Variations in the Fatty Acid Composition (FAC). The GC/FID chromatogram showing the FAC composition of fresh palm olein is exhibited in Figure 7, and the impact of processing on the FAC of this same oil is presented in Table 1. It can be observed that the fatty acid that was significantly affected by the treatment is linoleic acid (LA). In fresh oil, the amount of linoleic acid was 10.55%. This value significantly dropped after 6 days of treatment at 180°C. The highest decrease was registered with both control and oil samples enriched with the synthetic antioxidant (BHT), while this phenomenon was considerably reduced in oils containing ginger extract. After six days of storage, linoleic



Data are presented as Mean ± Standard deviation (n = 3). [a-c]Values of the same storage day with different superscripts differ significantly at $p<0.05$

FIGURE 5: Changes in iodine value of palm olein enriched with different concentrations of ginger extract during storage at frying temperature. BHT: butylated hydroxytoluene; PO: palm olein; Zn.O: *Zingiber officinale* (ginger); control: palm olein without antioxidant; PO + $BHT_{200\ ppm}$: palm olein + 200 ppm BHT; PO + $Zn.O_{200ppm}$: palm olein + 200 ppm ginger root extract; PO + $Zn.O_{600ppm}$: palm olein + 600 ppm ginger root extract; PO + $Zn.O_{1000ppm}$: palm olein + 1000 ppm ginger root extract; PO + $Zn.O_{1400ppm}$: palm olein + 1400 ppm ginger root extract; PO + $Zn.O_{1800ppm}$: palm olein + 1800 ppm ginger root extract. Data are presented as mean ± standard deviation ($n = 3$). [a–c]values of the same storage day with different superscripts differ significantly at $p < 0.05$.



Data are presented as Mean ± Standard deviation (n = 3). [a-e]Values of the same storage day with different superscripts differ significantly at $p<0.05$

FIGURE 6: Variations in the acid value of palm olein enriched with different concentrations of ginger extract during storage at frying temperature. BHT: butylated hydroxytoluene; PO: palm olein; Zn.O: *Zingiber officinale* (ginger); control: palm olein without antioxidant; PO + $BHT_{200\ ppm}$: palm olein + 200 ppm BHT; PO + $Zn.O_{200ppm}$: palm olein + 200 ppm ginger root extract; PO + $Zn.O_{600ppm}$: palm olein + 600 ppm ginger root extract; PO + $Zn.O_{1000ppm}$: palm olein + 1000 ppm ginger root extract; PO + $Zn.O_{1400ppm}$: palm olein + 1400 ppm ginger root extract; and PO + $Zn.O_{1800ppm}$: palm olein + 1800 ppm ginger root extract. Values with different superscripts on the same days are significantly different at $p < 0.05$. Data are presented as mean ± standard deviation ($n = 3$). [a–e]values of the same storage day with different superscripts differ significantly at $p < 0.05$.

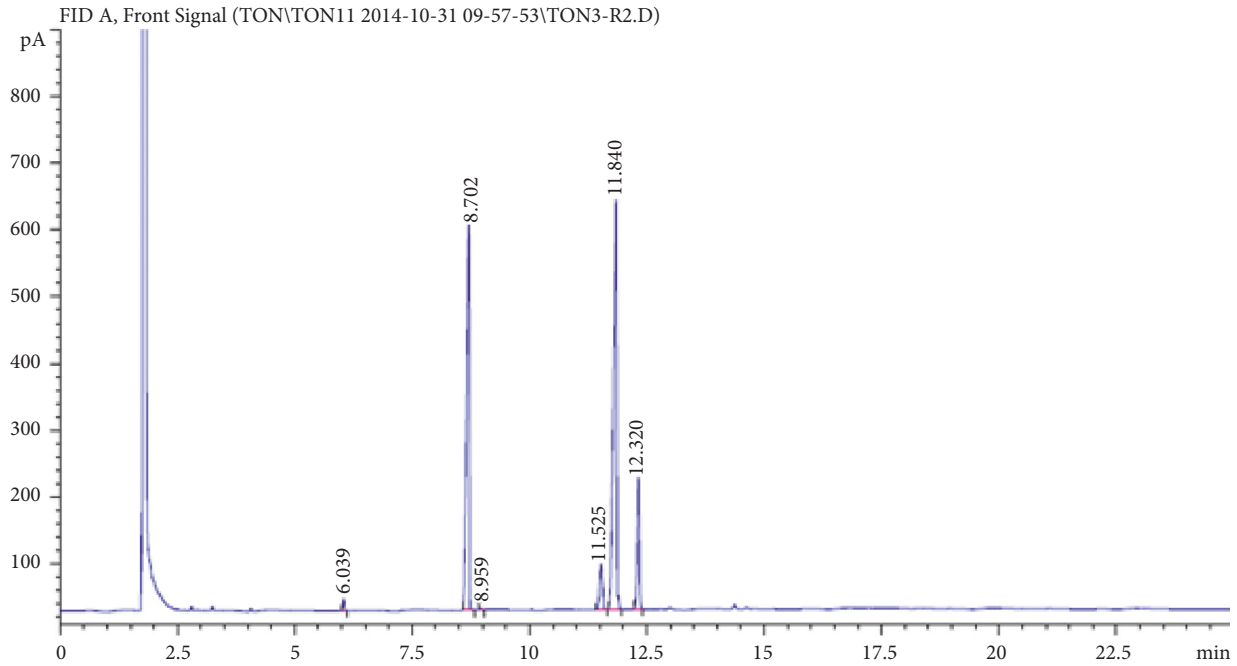


Figure 7: GC/FID chromatogram showing the fatty acid composition of palm olein. Identified fatty acids: myristic acid (C14 : 0) (1.75%, retention time: 6.030); palmitic acid (C16 : 0) (37.65%, retention time: 8.702); palmitoleic acid (C16 : 1) (0.15%, retention time: 8.959); stearic acid (C18 : 0) (4.75%, retention time: 11.525); oleic acid (C18 : 1) (46.09%, retention time: 11.840); and linoleic acid (C18 : 2) (10.55%, retention time: 12.320).

Table 1: Variations in fatty acid composition of palm olein samples.

Storage period (days)	Oil samples	Composition (%)					
		C14 : 0	C16 : 0	C16 : 1	C18 : 0	C18 : 1	C18 : 2
0	**PO**	0.75 ± 0.03^{a}	37.65 ± 0.06^{a}	0.15 ± 0.00^{a}	4.78 ± 0.03^{a}	46.09 ± 0.02^{a}	$\mathbf{10.55 \pm 0.01^{c}}$
	PO	0.73 ± 0.00^{a}	37.81 ± 0.00^{a}	0.14 ± 0.00^{a}	4.71 ± 0.07^{a}	46.34 ± 0.08^{a}	$\mathbf{10.24 \pm 0.01^{a}}$
	PO + BHT$_{200}$	0.76 ± 0.04^{a}	37.78 ± 0.05^{a}	0.16 ± 0.02^{a}	4.77 ± 0.03^{a}	46.21 ± 0.08^{a}	$\mathbf{10.29 \pm 0.04^{ab}}$
	PO + Zn.O$_{200}$	0.72 ± 0.00^{a}	37.81 ± 0.04^{a}	0.14 ± 0.00^{a}	4.81 ± 0.09^{a}	46.19 ± 0.00^{a}	$\mathbf{10.30 \pm 0.03^{ab}}$
2	**PO + Zn.O$_{600}$**	0.75 ± 0.03^{a}	37.66 ± 0.05^{b}	0.20 ± 0.08^{c}	4.76 ± 0.03^{a}	46.15 ± 0.14^{a}	$\mathbf{10.45 \pm 0.04^{c}}$
	PO + Zn.O$_{1000}$	0.72 ± 0.00^{a}	37.68 ± 0.01^{b}	0.26 ± 0.04^{b}	4.76 ± 0.01^{a}	46.18 ± 0.05^{a}	$\mathbf{10.37 \pm 0.03^{b}}$
	PO + Zn.O$_{1400}$	0.73 ± 0.02^{a}	38.04 ± 0.01^{c}	0.13 ± 0.01^{a}	4.69 ± 0.04^{b}	45.91 ± 0.03^{b}	$\mathbf{10.47 \pm 0.05^{c}}$
	PO + Zn.O$_{1800}$	0.73 ± 0.01^{a}	37.69 ± 0.02^{b}	0.15 ± 0.01^{a}	4.76 ± 0.02^{a}	46.13 ± 0.04^{a}	$\mathbf{10.51 \pm 0.06^{c}}$
	PO	0.75 ± 0.02^{a}	37.97 ± 0.09^{a}	0.24 ± 0.01^{a}	4.84 ± 0.09^{a}	46.23 ± 0.10^{a}	$\mathbf{9.94 \pm 0.08^{a}}$
	PO + BHT$_{200}$	0.74 ± 0.02^{a}	37.88 ± 0.03^{a}	0.23 ± 0.04^{a}	4.78 ± 0.00^{a}	46.34 ± 0.02^{a}	$\mathbf{9.99 \pm 0.00^{a}}$
	PO + Zn.O$_{200}$	0.61 ± 0.14^{a}	37.89 ± 0.03^{a}	0.16 ± 0.00^{b}	4.80 ± 0.02^{a}	46.32 ± 0.02^{a}	$\mathbf{10.19 \pm 0.07^{b}}$
4	**PO + Zn.O$_{600}$**	0.74 ± 0.00^{a}	37.75 ± 0.04^{b}	0.14 ± 0.00^{b}	4.72 ± 0.04^{a}	46.38 ± 0.08^{a}	$\mathbf{10.24 \pm 0.00^{b}}$
	PO + Zn.O$_{1000}$	0.72 ± 0.00^{a}	37.67 ± 0.08^{b}	0.14 ± 0.00^{b}	4.87 ± 0.16^{a}	46.28 ± 0.02^{a}	$\mathbf{10.29 \pm 0.05^{b}}$
	PO + Zn.O$_{1400}$	0.74 ± 0.01^{a}	37.71 ± 0.05^{b}	0.17 ± 0.02^{b}	4.72 ± 0.04^{a}	46.35 ± 0.11^{a}	$\mathbf{10.28 \pm 0.00^{b}}$
	PO + Zn.O$_{1800}$	0.73 ± 0.00^{a}	37.77 ± 0.02^{b}	0.14 ± 0.00^{b}	4.77 ± 0.00^{a}	46.32 ± 0.04^{a}	$\mathbf{10.24 \pm 0.03^{b}}$
	PO	0.74 ± 0.00^{a}	38.31 ± 0.06^{a}	0.14 ± 0.01^{a}	4.84 ± 0.05^{a}	46.28 ± 0.04^{a}	$\mathbf{9.65 \pm 0.06^{a}}$
	PO + BHT$_{200}$	0.73 ± 0.00^{a}	38.05 ± 0.05^{b}	0.17 ± 0.03^{a}	4.86 ± 0.09^{a}	46.40 ± 0.03^{b}	$\mathbf{9.75 \pm 0.04^{a}}$
	PO + Zn.O$_{200}$	0.73 ± 0.00^{a}	38.01 ± 0.02^{b}	0.13 ± 0.02^{a}	4.84 ± 0.07^{a}	46.39 ± 0.01^{b}	$\mathbf{9.89 \pm 0.04^{b}}$
6	**PO + Zn.O$_{600}$**	0.72 ± 0.02^{a}	37.89 ± 0.02^{c}	0.17 ± 0.01^{a}	4.79 ± 0.03^{a}	46.40 ± 0.03^{b}	$\mathbf{10.00 \pm 0.04^{c}}$
	PO + Zn.O$_{1000}$	0.75 ± 0.02^{a}	37.86 ± 0.08^{cd}	0.11 ± 0.01^{b}	4.80 ± 0.03^{a}	46.35 ± 0.02^{b}	$\mathbf{10.10 \pm 0.01^{d}}$
	PO + Zn.O$_{1400}$	0.72 ± 0.00^{a}	37.90 ± 0.03^{c}	0.15 ± 0.01^{a}	4.79 ± 0.05^{a}	46.27 ± 0.02^{a}	$\mathbf{10.13 \pm 0.02^{d}}$
	PO + Zn.O$_{1800}$	0.77 ± 0.07^{a}	37.79 ± 0.02^{d}	0.37 ± 0.09^{c}	4.78 ± 0.03^{a}	46.13 ± 0.09^{c}	$\mathbf{10.13 \pm 0.05^{d}}$

Data are presented as mean (±SD) ($n = 3$). $^{(a-d)}$means within each column, for each day with different superscripts differ considerably at $p < 0.05$. BHT: butylated hydroxytoluene; Zn.O: *Zingiber officinale* (ginger); control: palm olein without antioxidant; PO + BHT$_{200\ ppm}$: palm olein + 200 ppm BHT; PO + Zn.O$_{200ppm}$: palm olein + 200 ppm ginger root extract; PO + Zn.O$_{600ppm}$: palm olein + 600 ppm ginger root extract; PO + Zn.O$_{1000ppm}$: palm olein + 1000 ppm ginger root extract; PO + Zn.O$_{1400ppm}$: palm olein + 1400 ppm ginger root extract; PO + Zn.O$_{1800ppm}$: palm olein + 1800 ppm ginger root extract.

acid (LA) was found to be 10.13% in PO + Zn.$O_{1800ppm}$, 10.13% in PO + Zn.$O_{1400ppm}$, 10.10% in PO + Zn.$O_{1000ppm}$, 10.00% in PO + Zn.O_{600ppm}, and 9.89% in PO + Zn.O_{200ppm}, while in the control and oil sample containing the BHT, these values were, respectively, 9.65 and 9.89%. The extract seems to have played a positive role in linoleic acid preservation during storage at frying temperature compared with the control and the oil complemented with the BHT. Its activity was proportional to its concentration. This outcome is in line with the result of Che man and Tan [32], who obtained similar trends with LA in palm olein models enriched with rosemary and sage extracts throughout frying, and the extracts were best compared with BHA and BHT. The considerable drop in linoleic acid concentration recorded in the fresh and processed oil samples can be the consequence of lipid oxidation reactions that have damaged some of them to form oxidation products. No important variations were established in the concentration of other fatty acids during the treatment. This can be explained by their better resistance against oxidation reactions, since these are either saturated or monounsaturated fatty acids, which are recognized for having a better resistance towards thermal alteration reactions compared with polyunsaturated FAs such as linoleic acid. Generally, the good thermal resistance of ginger bioactives can justify the protective effect registered with linoleic acid. Comparable outcomes were previously reported by Djikeng et al. [14].

4. Conclusion

This study aimed at evaluating the aptitude of different concentrations of *Zingiber officinale* extract in inhibiting palm olein thermooxidation during storage at frying temperature. The results showed that the plant extract was effective in limiting palm olein alteration and was the best in preserving its linoleic acid content. Its activity was concentration-dependent, and it exhibited good thermal stability compared with the butylated hydroxytoluene. The good protective action of ginger root methanolic extract makes it an interesting source of antioxidants for the preservation of palm olein during processing. This study provides significant data that can motivate local producers and the industry to start looking forward to using this plant extract to extend the shelf life of their oils and their derivative products. This might encourage consumers to like the product more as it will be natural and safe. However, additional studies need to be carried out to evaluate the toxicity of palm olein complemented with ginger root methanolic extract as food additive and at the concentrations of 200, 600, 1000, 1400, and 1800 ppm.

Abbreviations

BHT: Butylated hydroxytoluene
PO: Palm olein
Zn.O: *Zingiber officinale* (ginger)
Control: Palm olein without antioxidant
PO + $BHT_{200\ ppm}$: Palm olein + 200 ppm BHT
PO + Zn.O_{200ppm}: Palm olein + 200 ppm ginger root extract
PO + Zn.O_{600ppm}: Palm olein + 600 ppm ginger root extract
PO + Zn.$O_{1000ppm}$: Palm olein + 1000 ppm ginger root extract
PO + Zn.$O_{1400ppm}$: Palm olein + 1400 ppm ginger root extract
PO + Zn.$O_{1800ppm}$: Palm olein + 1800 ppm ginger root extract.

Data Availability

Data are available from the authors up on request.

Conflicts of Interest

The authors declare that no conflicts of interest exist.

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