

Date	Submitted	Accepted	Published
	24 th August 2025	17 th September 2025	6 th November 2025

**PHYTOCHEMICALS, ANTIOXIDANT ACTIVITY, SENSORY ACCEPTABILITY
AND OXIDATIVE STABILITY OF PALM OLEIN SUPPLEMENTED WITH
GINGER (*Zingiber officinale*) RHIZOME EXTRACT**

Munyeke BM^{1*}, Owaga EE¹ and BW Mugendi²



Bernadette M. Munyeke

*Corresponding author email: bernadettemunyeke@gmail.com

ORCID: <https://orcid.org/0009-0007-8779-8674> - Munyeke BM

ORCID: <https://orcid.org/0000-0003-2360-4563> - Owaga EE

ORCID: <https://orcid.org/0000-0002-3096-843X> - Mugendi BW

¹Institute of Food Bio-resources Technology, Dedan Kimathi University of Technology (DeKUT), Private Bag, 10143, Dedan Kimathi, Nyeri, Kenya

²Murangá University of Technology, P.O. Box 75-10200, Murang'a, Kenya



ABSTRACT

Lipid oxidation is a major cause of quality deterioration in edible oils, driving demand for safe, natural alternatives to synthetic antioxidants such as butylated hydroxytoluene (BHT), which are limited by thermal instability and potential toxicity. This study investigated the effect of ginger (*Zingiber officinale*) rhizome extract on phytochemical composition, antioxidant activity, sensory acceptability, and oxidative stability of palm olein under accelerated oxidation storage. The bioactive profile of the extract was characterized, and the extract incorporated into additive-free palm olein at 200, 400 and 800 ppm, with BHT at 200 ppm as the positive control. The palm olein treatments were stored at 180°C for 5 consecutive days, with 4 hours of heating per day, to simulate accelerated oxidation. Oxidative stability was assessed by determining acid value (AV), peroxide value (PV), saponification value (SV), refractive index (RI), *p*-Anisidine value (*p*-AV), total oxidation (TOTOX), conjugated dienes (CD) and conjugated trienes (CT). The ginger rhizome extract (TPC: 136.27± 0.99 mg GAE/g; TFC: 439.41± 0.67 mg QE/g) exhibited strong antioxidant potential with an IC₅₀ of 0.12± 0.04 mg/ml, which correlated positively with its total phenolic and flavonoid content. The BHT significantly suppressed the formation of primary and secondary oxidation products more effectively than ginger rhizome extract at lower concentrations, as indicated by significantly lower *p*-AV and CD extinction coefficient values than all other treatments. However, the ginger rhizome extract exhibited a broader protective capacity, especially at 800 ppm, significantly reducing hydrolytic degradation, as measured by AV and SV, and limiting PV and CT extinction coefficient, by Day 5 of the accelerated oxidation storage. For TOTOX values, the PC maintained significantly lower values than all other treatments. These results demonstrate that while synthetic BHT acts mainly as a free-radical scavenger, ginger rhizome extract provides a multifaceted oxidative protection mechanism, improving both shelf life and sensory quality of palm olein, and represents a promising natural antioxidant for edible oil preservation.

Key words: Ginger extract, palm olein, antioxidants, oxidative stability, phytochemicals, sensory acceptability

Citation: Munyeki BM, Owaga EE and BW Mugendi Phytochemicals, Antioxidant Activity, Sensory Acceptability and Oxidative Stability of Palm Olein Supplemented with Ginger (*Zingiber officinale*) Rhizome Extract. *Afr. J. Food Agric. Nutr. Dev.* 2025; **25(9)**: 27842-27867.
<https://doi.org/10.18697/ajfand.146.26275>



INTRODUCTION

Edible oils are an integral part of the human diet, providing essential fatty acids and energy [1]. Palm oil, the most produced and marketed vegetable oil worldwide due to its high productivity and good oxidative stability, makes palm olein a preferred cooking medium in commercial food processing and frying operations [1, 2]. A key limiting factor in the optimal use of fats and oils is the rapid oxidation of unsaturated fatty acids, degrading the oil quality [3]. Exposure to high temperature, oxygen, light and moisture accelerates reactions that produce undesirable compounds (free fatty acids, peroxides, aldehydes, cyclic compounds and trans-fatty acids), negatively affecting oil nutritional and quality attributes [4]. Furthermore, the oil's primary oxidation products oxidize to secondary oxidation products, including core aldehydes and mono-epoxy oleic acids, which can induce toxicity and oxidative stress in humans [5].

To retard lipid oxidation, antioxidants are added during manufacturing. While synthetic antioxidants such as BHT are widely used in the edible oils industry, safety concerns regarding their instability and potential formation of chemical compounds with carcinogenic and toxic effects during high temperatures have increased demand for natural antioxidants [4, 5].

As a widely recognized spice and medicinal plant, ginger (*Zingiber officinale*) has been widely studied for its bioactive constituents, including essential oils, oleoresins, phenols, proteolytic enzymes, minerals and vitamins. The biological activities of ginger include antioxidant, antimicrobial, anti-inflammatory, anticancer, antidiabetic, neuroprotective, respiratory and cardiovascular protection [6].

Recently, there has been an increasing demand for healthier and natural alternatives to synthetic antioxidants, which face safety concerns [2]. However, there are limited studies on ginger rhizome extract, specifically in stabilizing palm olein during accelerated oxidation storage and its impact on the oil's acceptability and oxidative parameters. This study, therefore, aimed to determine the effect of ginger rhizome extract on the phytochemicals, antioxidant activity, sensory acceptability and stability of palm olein.

MATERIALS AND METHODS

Materials

Fresh, mature ginger rhizomes (local yellow-fleshed variety) were obtained from identified farmers in Naromoru region, Kieni East subcounty, Nyeri county. Additive-free palm olein was obtained from an edible oil manufacturing company in Kenya and transported to the Institute of Food Bioresources Technology, Dedan Kimathi University of Technology (DeKUT).



Ginger rhizome preparation and extraction of bioactive components

The ginger rhizomes were washed, grated, and dried in a forced-air drying oven (UOV-230F, UMS- UK) at 50°C for 48 hours. Following drying, the sample was ground into a fine powder and passed through a 0.5mm diameter mesh [7].

Extraction of ginger bioactive components followed the modified method by Kedir *et al.* [2]. Briefly, the powder (200 g) was soaked in ethanol (1 L) at room temperature, with shaking at 250 rpm using an IKA KS250 basic mechanical shaker (IKA-Werke GmbH and Co. KG, Staufen, Germany) for 24 hours. Ethanol is classified as a 'green solvent', offering a sustainable, food-safe and effective alternative to petroleum-based solvents, thus selected as the extraction solvent [8]. Following extraction, the solvent was filtered, and the filtrate concentrated using a Bibby RE100 rotary evaporator (Bibby Scientific Ltd., Stone, UK) at 60°C and 90 rpm to a highly viscous concentrate, then dried at room temperature. The crude extract yield was calculated as described by Samudin *et al.* [9]. The extract was stored at -20°C, in air-tight amber glass bottles until used.

Experimental design and oil samples preparation

A laboratory-based, comparative experimental design was used for the study. All the analyses were conducted in the laboratory and data were collected using approved experimental procedures. According to the *Codex Alimentarius* Commission, synthetic antioxidants are permitted at up to 200 ppm in edible fats and oils [10]. Ginger rhizome extract (200, 400 and 800 ppm) and BHT (200 ppm) were added to prepare the oil samples using Djikeng *et al.* [11] treatments with minor modifications (Table 1).

Determination of total phenolics

The total phenolics in the ginger rhizome extract and palm olein treatments were determined using the Folin-Ciocalteu method as described by Alhakmani *et al.* [12] with minor modifications. A mixture of 1ml of each extract, 2 ml of Folin-Ciocalteu reagent and 4ml of sodium carbonate solution (7.5%, w/v) was incubated in the dark for two hours. The absorbance of the incubated mixtures was measured at 765 nm using a Shimadzu UV-1800 spectrophotometer (Shimadzu Corporation, Kyoto, Japan). Using a gallic acid standard curve ($R^2 = 0.999$), the total phenolics were determined and expressed in mg gallic acid equivalent (GAE) /g of the sample.

Determination of total flavonoids

Total flavonoids in the ginger rhizome extract and palm olein treatments were determined using the aluminium chloride colorimetric method as described by Akullo *et al.* [13]. A spectrophotometer (Shimadzu UV-1800, Shimadzu Corporation, Kyoto, Japan) was used to detect absorbance at 415 nm. Total flavonoids were determined using a quercetin standard curve, with a linearity range of 0 to 1000 µg/ml ($R^2 =$



0.994). The total flavonoids were reported in mg of quercetin equivalent (QE)/g of sample.

DPPH (1,1-diphenyl-2-picrylhydrazyl) free radical scavenging assay

The ability of the crude ginger rhizome extract and palm olein treatments to scavenge the stable DPPH free radical was determined using the modified method of Moga *et al.* [14]. Briefly, 1 ml of 1-20 mg/ml concentrations of extract solution and prepared oil samples were added to 2 ml of 0.1mM DPPH solution in methanol and absorbance was measured at 517 nm using a spectrophotometer (Shimadzu UV-1800, Shimadzu Corporation, Kyoto, Japan). An equal amount of DPPH and methanol was prepared as the blank. Quercetin and BHT were used as the reference standard. The antioxidant activity as % scavenging of DPPH was calculated as follows:

$$\% \text{ Scavenging of DPPH} = (A_c - A_s) / A_c \times 100 \quad (1)$$

Where A_c and A_s are the control and sample absorbance, respectively.

A dose-response curve was plotted to determine the concentration required for 50% scavenging capacity (IC_{50}).

Sensory evaluation and consumer acceptability of palm olein treatments

Sensory acceptability of the palm olein treatments was conducted at the Food Science Workshop, Dedan Kimathi University of Technology, immediately after adding the antioxidants. A total of 43 semi-trained panellists ($n = 23$ males, $n = 20$ females) were recruited through voluntary response sampling and selected based on their willingness and availability to participate. Before participating, all the panelists provided informed consent, received training on the sensory evaluation procedures and familiarized themselves with the hedonic scales.

Approximately 20ml of each oil sample was served in a 50ml clear cup and coded with randomized three-digit numbers. Panelists evaluated appearance, aroma, aroma persistence and overall liking using a 9- point hedonic scale (1=Dislike extremely, 9= Like extremely). Consumer purchase intention was rated on a 5-point hedonic scale (1=Definitely would not buy, 5= Definitely would buy).

Accelerated oxidation storage

The accelerated oxidation storage for the treatments followed a modified oven test method [11]. All treatments were introduced in a forced-air drying oven (DFO-240, MRC Ltd., Israel) and heated for five days at 180°C (4 hrs/ day). Oil samples were collected at five time points: FO (fresh palm olein without any added antioxidants), T0 (palm olein with added antioxidants, immediately after preparation) and at days 1, 3 and 5. All samples were stored at 4°C for analysis of acid value (AV), peroxide



value (PV), saponification value (SV), refractive index (RI), *p*-anisidine value (*p*-AV), total oxidation (TOTOX) value, conjugated dienes (CD) and conjugated trienes (CT).

Determination of oxidative stability

The oxidative stability of the olein samples was assessed by determining various quality parameters. The AV and PV were determined by titration methods [15]. A titrimetric method was used to assess the SV [16]. The RI determination followed a method described by Wazed *et al.* [17], using an ATAGO refractometer (ATAGO Co., Ltd., Tokyo, Japan). The *p*-AV was determined subsequently by measuring absorbance at 350 nm using a Shimadzu UV-1800 spectrophotometer (Shimadzu Corporation, Kyoto, Japan), as described by Patil *et al.* [18]. Overall oxidative degradation (TOTOX) was determined as described by Sharanke and Sivakanthan [19]. The study additionally determined CDs and CTs based on absorbance readings taken at 232 nm and 268 nm, respectively, as reported by Ramroudi *et al.* [20]. The obtained values were used to calculate the specific extinction coefficients for CDs and CTs, respectively, as follows:

$$K\lambda = E\lambda / (c \times s) \quad (2)$$

Where $K\lambda$ is the specific extinction at wavelength λ , $E\lambda$ is the extinction measured at wavelength λ , c is the solution concentration (g /100ml) and s is the path length of the quartz cell (cm).

Statistical analyses

All the chemical analyses were conducted in triplicate and the results were expressed as mean \pm standard deviation (SD). Minitab software was used for one-way analysis of variance (ANOVA) for the data. Pearson's correlation was used for the correlation studies. For significant ANOVA results, Fisher's Least Significant Difference (LSD) and Tukey's HSD tests were used to compare means among treatments for chemical analyses and sensory evaluation data, respectively. Differences were considered statistically significant at $p < 0.05$.

RESULTS AND DISCUSSION

Total extraction yield

The total extraction yield from the dried ginger rhizome was 3.63 ± 0.50 %, consistent with the 3.6% yield for *Zingiber Officinale* extract using ethanol and the maceration, reported by Al-Areer *et al.* [21]. A higher extraction yield of 17.70 ± 1.78 % has been previously recorded for *Zingiber officinale* rhizomes using ethanol and Soxhlet extraction [22]. The difference in yield among different studies could be due to the type of solvent used, plant species, sample particle size, sample ratio to solvent amount, time and extraction method [23].



After the conventional extraction, the biomass (residue) can undergo secondary extractions like subcritical and supercritical CO₂ extraction to maximize the recovery of bioactive compounds, contributing to achieving circular economy goals. After the secondary extraction, the residual biomass can be used as a biofertilizer or pest-repelling compound [22].

Total phenolic content (TPC), total flavonoid content (TFC) and antioxidant activity of crude ginger rhizome extract

The TPC, TFC and antioxidant activity obtained for ginger rhizome extract are shown in Table 2. The ginger rhizome extract had a TPC of 136.27 ± 0.99 mg GAE/g and a TFC of 439.41 ± 0.67 mg QE/g, highlighting the richness of phenolic and flavonoid compounds in the concentrated crude extract. The TPC is comparable to 142.91 mg GAE/g (maceration) and different from 96.67 mg GAE/g (Soxhlet), reported by Al-Areer *et al.* [21]. Another study reported a higher TPC (151.55 ± 0.71 mg GAE/g) for ginger root than that of the current study [24].

Several studies reported lower TFC in ginger root, with values of 57.25 ± 0.08 mg QE/g [24] and 45.66 ± 1.80 mg QE/g [25], compared to the current study level of 439.41 ± 0.67 mg QE/g. However, higher TFC values of 700 mg QE/g and 513.3 mg QE/g for maceration and soxhlet methods, respectively, were reported in a previous study [21]. Sources of variability of the current study, TPC and TFC from previous studies, could be attributed to cultivars, growing conditions, geographic area, maturity state, extraction method and solvent polarity [2, 26].

The antioxidant activity of the ginger rhizome extract was evaluated using IC₅₀, the concentration required to inhibit 50% free radicals in an assay [27] and compared with synthetic antioxidants BHT and quercetin (QCT) (Table 2). The BHT exhibited the highest IC₅₀ and was significantly different from both the QCT and the extract. However, the IC₅₀ value of ginger rhizome extract was not significantly different from that of QCT. These study findings suggest that in an isolated free-radical scavenging assay, the antioxidant potential of ginger rhizome extract is comparable to quercetin and significantly better than BHT.

A study reported a higher IC₅₀ of 0.48 ± 0.09 mg GAE/g for ginger rhizome extracted using ethanol and reflux extraction [24]. Another study reported IC₅₀ of 0.499 ± 0.021 mg/ml and 0.548 ± 0.045 mg/ml for ginger from Ayikel and Mandura towns in Ethiopia, respectively [26], which are higher than the levels of the current study. The variations in antioxidant activity can be associated with the type and polarity of solvent, isolation method, purity of the bioactive ingredient, interactions of an antioxidant component with other chemicals in the medium and the testing system [24].



Total phenolic, flavonoid and antioxidant activity of palm olein treatments

The TPC, TFC and antioxidant activity obtained for the palm olein treatments are shown in Table 3. The negative control (NC) showed detectable TPC and TFC, possibly due to naturally occurring palm-based phytochemicals, such as phenolics [28]. The TPC and TFC of the NC and positive control (PC) had no significant differences, possibly due to structural differences between natural phenolic compounds and synthetic antioxidants [29], indicating that adding BHT did not contribute to measurable levels of phenolics and flavonoids.

Total phenolic content (TPC) and total flavonoid content (TFC) increased with the extract concentration among the ginger-treated olein samples. While the TPC and TFC of GR200 were not significantly different from the controls, GR400 and GR800 had significantly higher values than GR200 and controls, with GR800 having the highest values among the treatments. These study findings demonstrate the ginger rhizome extract's ability to contribute to the palm olein's total phenolics and flavonoids, potentially translating to improved antioxidant activity [2, 13].

The NC showed significantly high IC_{50} , confirming its minimal radical scavenging ability. The ginger extract treatments demonstrated a concentration-dependent improvement in antioxidant activity. The GR800 had the lowest IC_{50} , significantly different from GR200 and GR400. Notably, there was no significant difference between the IC_{50} values of the PC and GR800, suggesting that ginger rhizome extract may effectively compare with synthetic antioxidants in performance.

Correlation of antioxidant activity with total phenolic and flavonoid content

A Pearson correlation analysis investigated the relationship between the TPC/TFC and the IC_{50} values in the ginger rhizome extract and palm olein samples treated with ginger extract. The results showed a strong negative correlation between the TPC/TFC and IC_{50} (Table 4), suggesting that enhanced antioxidant capacity is associated with higher levels of phenolics and flavonoids [27]. However, the p -values were greater than the conventional significance level ($p < 0.05$); therefore, the correlation was not statistically significant. A previous study obtained similar findings of a strong negative correlation between phenolic and flavonoid variables and IC_{50} [27].

Effects of ginger rhizome extract on sensory attributes and purchase intention of palm olein treatments

Appearance scores of GR200 were significantly higher than the other treatments and lowest in GR800 (Figure 1), indicating that a moderate extract level produced a visually acceptable product and vice versa. This inverse relationship is commonly observed with concentrated natural extracts, as excessive pigment load can lead to darkening [30].



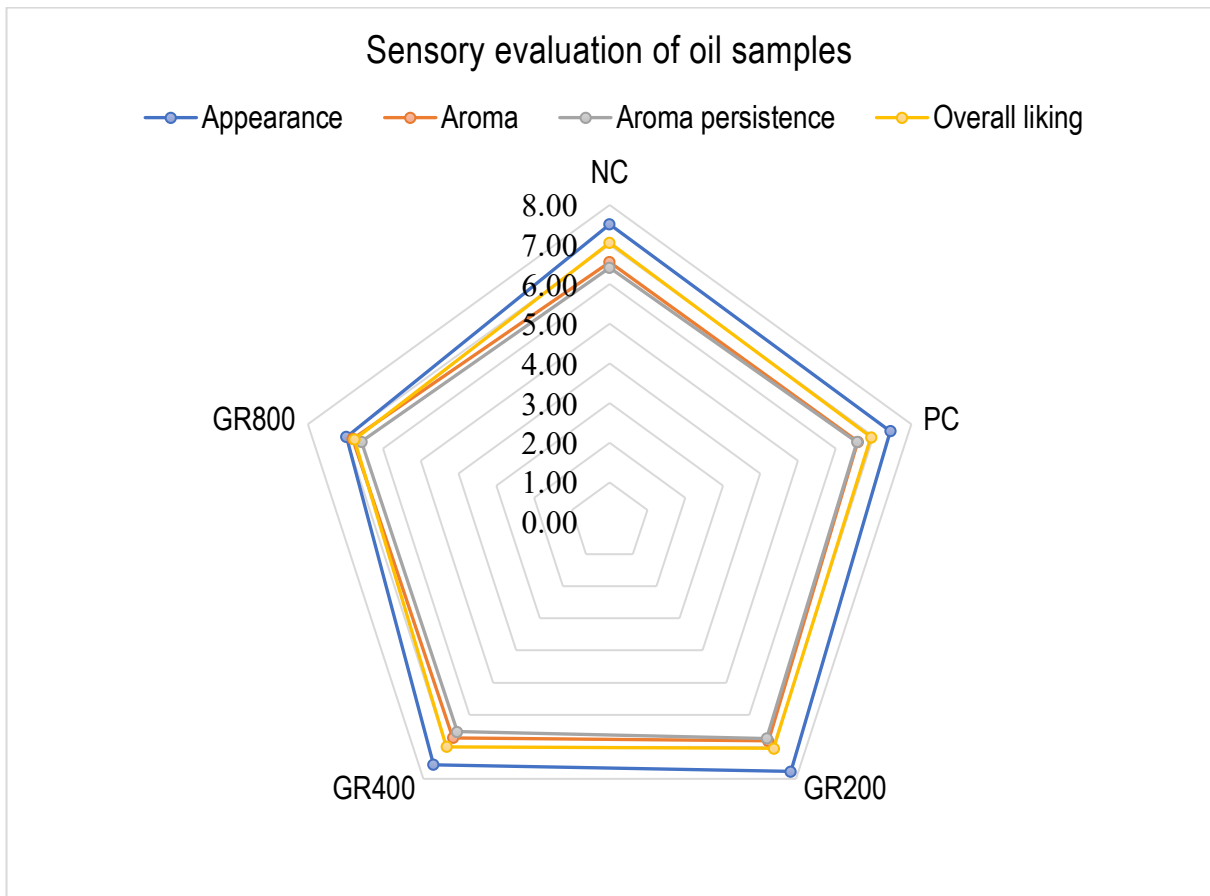


Figure 1: Mean scores for the sensory attributes of palm olein treated with different concentrations of ginger rhizome extract and controls. NC: Negative control (palm olein with no added antioxidant), PC: Positive control (palm olein with 200 ppm BHT); GR200, GR400, GR800: palm olein with 200ppm, 400ppm and 800ppm ginger rhizome extract, respectively

The lack of significant difference in aroma and aroma persistence scores among the different ginger extract concentrations, despite a perceived improvement over controls, could be due to the panelists reaching a threshold where higher concentrations do not proportionally translate to greater perceived intensity or possibly due to sensory saturation [31]. However, high aroma scores recorded by the GR200 and GR800 than the NC and PC suggest that the aromatic quality of the palm olein was enhanced, possibly due to the characteristic aroma of volatile compounds present in ginger [32]. No significant differences in the overall liking across all treatments, indicating that ginger rhizome extract did not affect the overall acceptability of the palm olein.

The consumers purchase intention scores presented in Table 5 were highest for GR200, followed by GR400, suggesting that moderate addition of ginger rhizome

extract positively influences consumer purchasing decisions. However, all treatments had no significant differences due to the overlapping statistical groups.

Effect of ginger rhizome extract on the stability of palm olein

Acid value (AV)

The treatments' AV (mg KOH/g) were monitored over accelerated oxidation storage (Figure 2). The FO and Day 0 AVs had no significant differences, with values (0.44-0.50 mg KOH/g oil) lower than the *Codex Alimentarius* (1999) recommended level (AV > 0.6mg/g) [5], indicating minimal initial degradation. A general increase in AV of all treatments over time was due to triglyceride hydrolysis into FFAs [5].

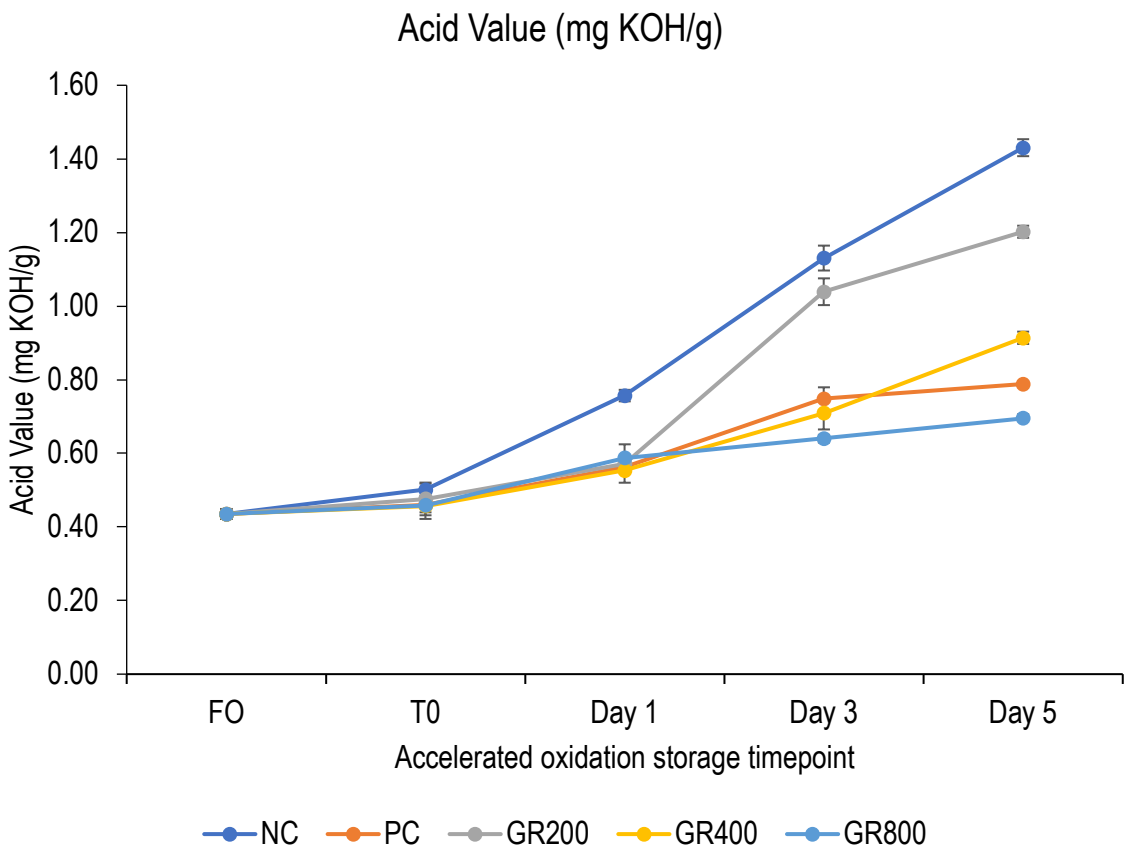


Figure 2: Changes in acid value of palm olein treated with different concentrations of ginger rhizome extract and controls during 5-days accelerated oxidation storage. NC: Negative control (palm olein with no added antioxidant); PC: Positive control (palm olein with 200 ppm BHT); GR200, GR400, GR800: palm olein with 200ppm, 400ppm and 800ppm ginger rhizome extract respectively; FO: Fresh oil (palm olein with no added antioxidant); T0: palm olein with added antioxidants, immediately after preparation



The increase was significantly higher in NC, compared to all other treatments over time, suggesting rapid hydrolytic degradation due to the absence of antioxidants [33]. The ginger rhizome extract-treated palm olein showed a dose-dependent protective effect, with the GR800 consistently maintaining the lowest AV, indicating its superior antioxidant activity compared to the other treatments.

The PC demonstrated moderate protection, exhibiting a final AV (Day 5) significantly lower than NC, but higher than GR800, indicating that PC significantly reduced FFA formation; however, GR800 was more effective. The GR200 and GR400 demonstrated significantly ($p < 0.05$) lower AVs than the NC, from Day 3 onwards, underscoring ginger extract's efficacy in slowing hydrolytic degradation. The study findings suggest ginger rhizome extract, particularly at 800 ppm, is highly effective in mitigating AV increases, performing better than BHT.

Previous studies have reported consistent findings with the plant extracts inhibiting hydrolysis in a concentration-dependent effect [2, 5, 34]. A study by Djikeng *et al.* [11] reported a contrasting trend: a constant AV increase for 600–1800 ppm ginger-treated oil, but a significant increase on the second day, decline on the fourth day, followed by a rise on the sixth day for the NC, 200 ppm ginger-treated oil and 600 ppm BHT-treated oil. These discrepancies are possibly due to the difference in the antioxidant concentration.

Peroxide value (PV)

The PV of the palm olein treatments was monitored during accelerated oxidation storage (Figure 3). Crucially, an initial reduction in PV was observed immediately after antioxidant addition (Day 0) for PC, GR200, GR400 and GR800, with the GR800 effect being more pronounced. This is possibly due to the additives scavenging existing free radicals [35]. In contrast, NC had an increased PV, attributable to a lack of antioxidant protection, rendering the oil vulnerable to immediate peroxide formation.

The NC consistently showed the highest PV increase, indicating rapid progression of lipid oxidation. In contrast, GR800 had a lower rate of PV increase than the NC and PC throughout, suggesting that 800ppm extract exerts a more potent stabilizing effect than PC. The enhanced activity of the GR800 could be due to the extract's vital antioxidant properties, better heat resistance and synergistic effects [35]. No significant differences were noted for the PVs of the PC and GR400 throughout the storage, indicating that they had comparable stabilizing effects.

Crucially, the PVs consistently remained within the recommended *Codex Alimentarius* limit of 10 meq/Kg [5], ranging from 0.22 meq/Kg to 1.81 meq/Kg throughout the storage. Previous studies have reported a similar PV trend of antioxidant-treated groups [11, 33, 35].



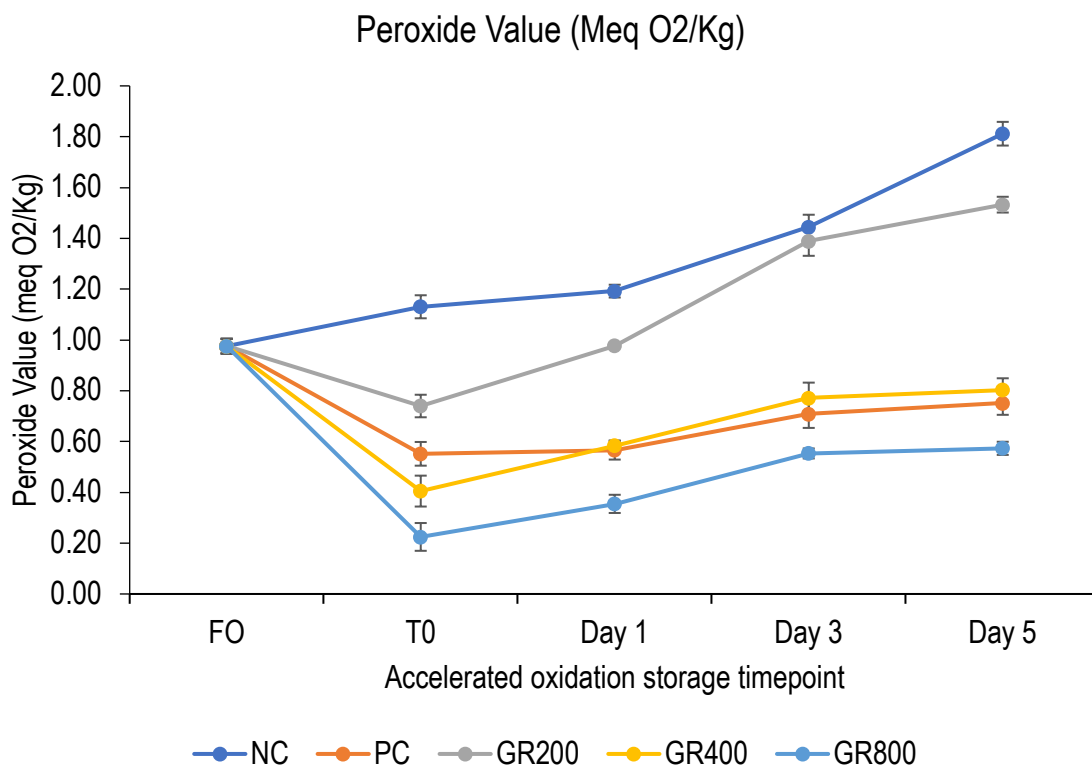


Figure 3: Changes in peroxide value of palm olein treated with different concentrations of ginger rhizome extract and controls during 5-days accelerated oxidation storage. NC -Negative control (palm olein with no added antioxidant); PC: Positive control (palm olein with 200 ppm BHT); GR200, GR400, GR800 - palm olein with 200ppm, 400ppm and 800ppm ginger rhizome extract respectively; FO: Fresh oil (palm olein with no added antioxidant); T0: palm olein with added antioxidants, immediately after preparation

Saponification value (SV)

The SVs assessed to evaluate the oxidative stability of palm olein treatments are presented in Table 6. No significant differences were noted initially for fresh oil (FO) and Day 0 SVs, establishing a uniform baseline. As the accelerated oxidation progressed, a general SV increase was observed in all treatments. The NC exhibited a substantial increase, indicating extensive fatty acid degradation in the absence of an antioxidant. The NC trend was mirrored by GR200, which showed no significant difference from the NC throughout, indicating a lower protective effect of the ginger extract at lower concentrations.

The PC showed a less distinct increase in SV, demonstrating the effectiveness of BHT in mitigating the oxidative breakdown of fatty acids, compared to NC. At the same time, GR400 and GR800 exhibited a lower SV increase than the PC

throughout. The GR800 demonstrated a better stabilization effect among all treatments, indicating its effectiveness in enhancing the palm olein's oxidative stability. These findings agree with those from a previous study that reported *Eucalyptus citriodora* leaf extract was more effective than the control in maintaining the oil unsaturation over time [34].

Refractive Index (RI)

Palm olein's RI increases due to the formation of conjugated dienes, trienes and non-volatile carbonyl products [5]. The RI values of oil treatments during accelerated oxidation storage are shown in Figure 4. All FO and Day 0 treatments were not significantly different, establishing a similar baseline RI. As the oxidation progressed, there was a general increase in RI in all treatments. The NC recorded significantly higher RI values than the ginger-added oils by Day 3 and 5, particularly GR400 and GR800, highlighting their effectiveness in delaying the oil oxidation. The slower RI increase in the extract-treated groups is attributable to the antioxidative phytochemicals in ginger, including essential oils, oleoresins, phenols, proteolytic enzymes and vitamins, which likely inhibited oxidized and polymerized triglycerides formation [6]. By Day 5, the PC, GR400 and GR800 RI values had no significant differences, indicating a comparable protective effect.

These findings agree with previously reported slow RI increase throughout incubation, with a slightly greater rise for the controls than for *Eucalyptus citriodora* leaf extract-treated oils [34]. Other studies on plant additive groups reported an insignificant effect on the RI of oils [5].



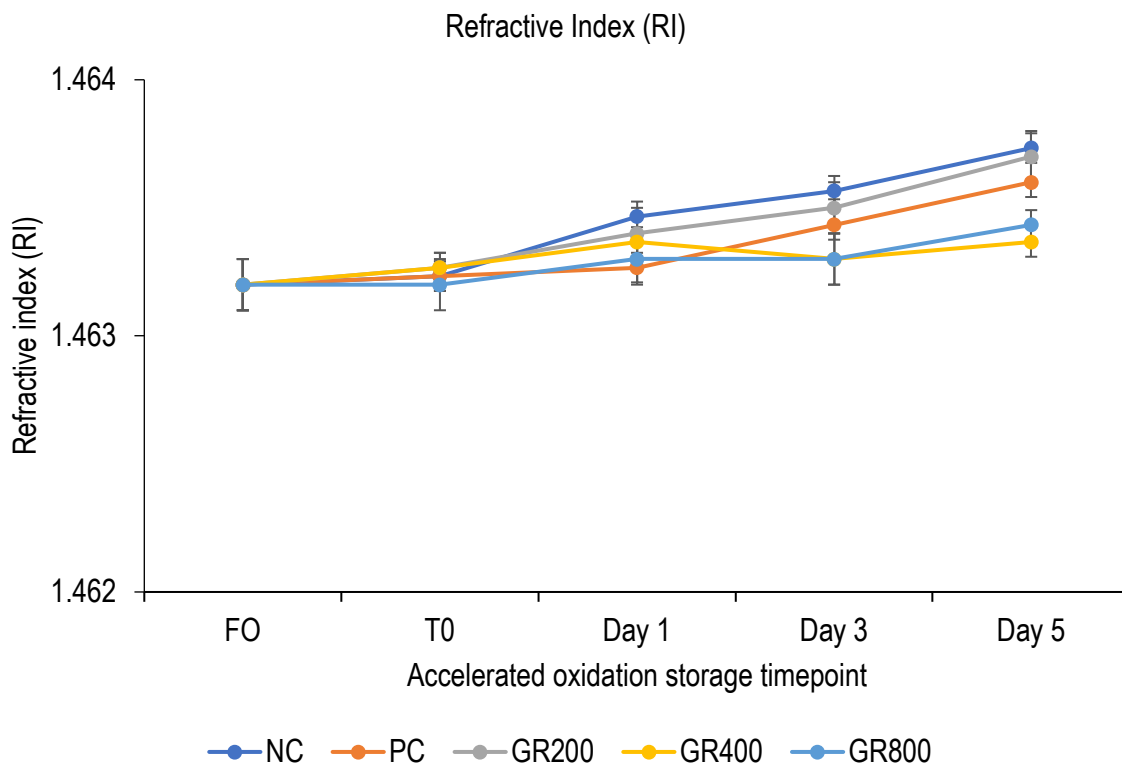


Figure 4: Changes in RI of palm olein treated with different concentrations of ginger rhizome extract and controls during 5-days accelerated oxidation storage. NC: Negative control (palm olein with no added antioxidant), PC: Positive control (palm olein with 200 ppm BHT); GR200, GR400, GR800: palm olein with 200ppm, 400ppm and 800ppm ginger rhizome extract respectively; FO: Fresh oil (palm olein with no added antioxidant); T0: palm olein with added antioxidants, immediately after preparation

p-Anisidine Value (p-AV)

As presented in Table 7, the p-AV of all the treatments increased throughout accelerated oxidation storage. The NC exhibited a pronounced increase from Day 0 to the highest value on Day 5, a phenomenon attributable to the formation of decomposition products of hydroperoxides, indicating higher secondary alteration, possibly due to the absence of added antioxidants [11]. The PC showed better inhibitory effects than ginger-treated oils throughout the accelerated oxidation storage. Unexpectedly, GR400 showed a greater inhibition of the formation of secondary compounds than GR800, possibly due to the saturation of the antioxidant capacity provided by the polyphenols within the extract – an effect previously reported in polyphenol-rich systems that higher concentrations may plateau or diminish beneficial effects [36].

The current study findings indicate that adding natural antioxidants could enhance the stability of palm olein, as determined by p-AV, which measures the presence of secondary oxidation products formed from hydroperoxide decomposition, especially aldehydes, ketones and carbonyls [11, 35]. Similar p-AV increases with oxidative stress trends and concentration-dependent inhibition have been reported in previous studies [5, 11, 37].

Total Oxidation (TOTOX) values

The changes in TOTOX values, which integrate both primary (PV) and secondary oxidation products (p-AV) [33, 38], of palm olein samples during accelerated oxidation storage are shown in Figure 5. The TOTOX values for all treatments increased over time, with the NC increase being more pronounced, reaching the highest value of 20.23 ± 0.08 on Day 5. The PC maintained significantly lower TOTOX values compared to the other treatments, from Day 1 to Day 5. Among the ginger-treated groups, the TOTOX values for GR400 were significantly different from GR800 by Day 5, with the GR400 performing better. The protective effect of the ginger rhizome extract is attributable to its ability to retard free radical damage [33].

Previous studies have reported that plant extracts significantly lower TOTOX values while recording significant TOTOX value increases for additive-free oil over storage time, supporting natural antioxidants' efficacy [33, 37].

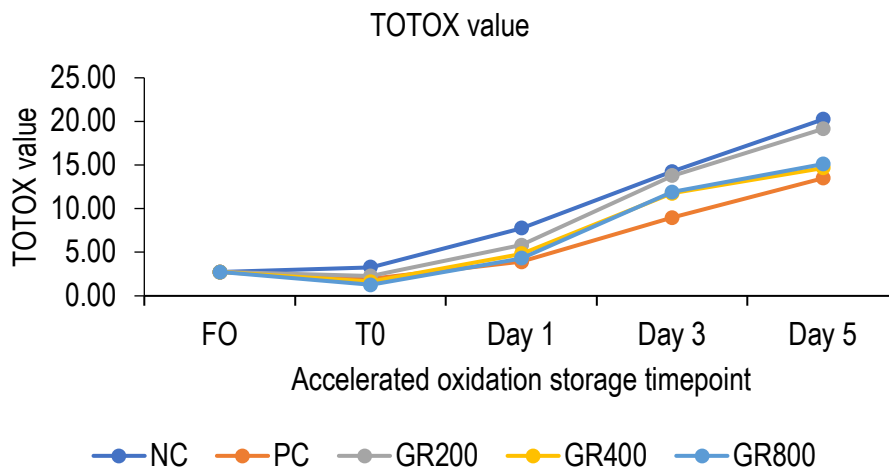


Figure 5: Changes in TOTOX values of palm olein treated with different concentrations of ginger rhizome extract and controls during 5-days accelerated oxidation storage. NC: Negative control (palm olein with no added antioxidant), PC: Positive control (palm olein with 200 ppm BHT); GR200, GR400, GR800: palm olein with 200ppm, 400ppm and 800ppm ginger rhizome extract, respectively; FO: Fresh oil (palm olein with no added antioxidant); T0: palm olein with added antioxidants, immediately after preparation

Extinction coefficients (K_{232} and K_{268})

The rearrangement of double bonds in monounsaturated and polyunsaturated fatty acids produces conjugated dienes (CDs) and conjugated trienes (CTs) in oil, respectively; with extinction coefficients K_{232} and K_{268} measuring CDs and CTs, respectively [38]. The extinction coefficients obtained are presented in Table 8. An overall increase in K_{232} and K_{268} observed signifies the formation of more conjugated dienes and trienes over time, with NC consistently demonstrating the highest values throughout. On Day 5, PC exhibited significantly lower K_{232} than the other treatments, followed by GR800, possibly due to the high antioxidant activity of the extracts and BHT that retarded the oxidation [5].

These findings align with those of previous studies [5, 37]. For instance, Abdo *et al.* [5] reported that pomegranate/orange/beetroot leaf extract significantly reduced the formation of CD compared to BHT; BHT was more effective against CT formation than the extract. Ahmed *et al.* [37] found that saffron stigmas lowered CT levels.

CONCLUSION AND RECOMMENDATIONS FOR DEVELOPMENT

Ginger (*Zingiber officinale*) rhizome extract significantly improved palm olein's antioxidant activity and oxidative stability under accelerated storage, providing broader and more multifaceted protection than synthetic BHT. This effectiveness was associated with the extract's high phenolic and flavonoid content, with strong negative correlations between IC_{50} values and both TPC and TFC.

Palm olein treatments with ginger rhizome extract at 400–800 ppm exhibited optimal oxidative stability while retaining desirable sensory qualities. The study therefore recommends industrial incorporation of ginger rhizome extract at 400–800 ppm in palm olein as a natural antioxidant alternative to, or partial replacement for, synthetic antioxidants.

Further investigations with a wider range of extract concentrations are needed to validate the suggested potential functional relationships between IC_{50} values and both TPC and TFC. Additionally, the current study sensory evaluation had geographical and demographical limitation, therefore, larger-scale consumer preference studies are advised to assess sensory acceptance and market viability across diverse demographic groups to support commercial adoption.

The study findings underscore the importance of developing policies and establishing guidelines promoting the use of natural antioxidants in edible oils by food regulatory bodies in Kenya and the regional East African Community (EAC). Such frameworks could facilitate industry uptake, enhance consumer protection, and align with global trends favoring clean-label, plant-based food preservation.



ACKNOWLEDGEMENTS

The invaluable technical support provided during this research by the staff and facilities of the Food Science and Technology laboratories at Dedan Kimathi University of Technology, Nyeri, Kenya and Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya, is gratefully acknowledged.

Conflict of interest

The authors declare no conflict of interest.

Ethical approval

Ethical approval for the study was obtained from the Dedan Kimathi University of Technology Scientific and Ethical Review Committee (DeKUTSERC) (approval number DeKUT/ISREC/03422/091) and the National Commission for Science, Technology and Innovation (NACOSTI) under reference number 679622. Participants gave consent to participate in the sensory evaluation.



Table 1: Experimental design for the ginger extract treatments in palm olein

Treatments	Ginger root extract (mg/Kg)/(ppm)	BHT (mg/Kg)/(ppm)
NC (Negative control)	0	0
PC (Positive control)	0	200
GR200	200	0
GR400	400	0
GR800	800	0

Note: NC: negative control (palm olein with no added antioxidant), PC: positive control (palm olein with 200 ppm of butylated hydroxytoluene (BHT)); GR200, GR400 and GR800: palm olein with 200 ppm, 400 ppm and 800 ppm of ginger rhizome extract, respectively

Table 2: Total phenolic content (mg GAE/g sample), total flavonoid content (mg QE/g sample) and IC₅₀ (mg/ml) of crude ginger rhizome extract

Sample	Total phenolic content (mg GAE/g sample)	Total flavonoid content (mg QE/g sample)	IC ₅₀ (mg/ml)
Ginger rhizome extract	136.27± 0.99	439.41± 0.67	0.12± 0.04 ^b
BHT	ND	ND	0.29± 0.08 ^a
QCT	ND	ND	0.07± 0.02 ^b

Note: Values are mean values ±SD. Means in the same column that do not share a superscript letter differ significantly (p< 0.05). BHT: butylated hydroxytoluene, QCT: Quercetin, ND: Not determined

Table 3: Total phenolic content (mg GAE/g sample), total flavonoid content (mg QE/g sample) and IC₅₀ (mg/ml) of palm olein treatments

Treatment	Total phenolic content (mg GAE/g sample)	Total flavonoid content (mg QE/g sample)	IC ₅₀ (mg/ml)
NC	1.47± 0.02 ^c	61.95± 0.88 ^d	43.56± 2.48 ^a
PC	1.45± 0.03 ^c	62.21± 0.97 ^{cd}	8.66± 0.72 ^d
GR200	1.50± 0.02 ^c	63.74± 0.26 ^c	30.90± 1.38 ^b
GR400	2.50± 0.03 ^b	69.97± 0.15 ^b	18.88± 2.69 ^c
GR800	2.88± 0.02 ^a	72.87± 0.13 ^a	8.10± 1.14 ^d

Note: Values are mean values ±SD. Means in the same column that do not share a superscript letter differ significantly (p< 0.05). NC: Negative control (palm olein with no added antioxidant), PC: Positive control (palm olein with 200 ppm BHT); GR200, GR400 and GR800: palm olein with 200ppm, 400ppm and 800ppm ginger rhizome extract, respectively

Table 4: Pearson Correlation Coefficients (r) and p-values between TPC, TFC and IC₅₀ of crude ginger rhizome extract and palm olein with different extract concentrations

Variables	Correlation Coefficient(r)	p-value
TPC and IC ₅₀	-0.723	0.277
TFC and IC ₅₀	-0.731	0.269

Correlations are considered statistically significant at p< 0.05. TPC: Total phenolic content, TFC: Total flavonoid content, IC₅₀: half maximal inhibitory concentration

Table 5: Purchase intention (1 = Definitely would not buy, 5 = Definitely would buy) of palm olein treatments and potato fries fried on Day 1

Treatment	Purchase Intention
NC	3.79±0.99 ^a
PC	3.88±0.79 ^a
GR200	3.95±0.93 ^a
GR400	3.91±1.27 ^a
GR800	3.86±1.30 ^a

Note: Values are mean values ±SD. Means in the same column that do not share a superscript letter differ significantly (p< 0.05). NC: Negative control (palm olein with no added antioxidant); PC: Positive control (palm olein with 200 ppm BHT); GR200, GR400, GR800: palm olein with 200ppm, 400ppm and 800ppm ginger rhizome extract, respectively

Table 6: Saponification value (mg KOH/g) levels during accelerated oxidation of palm olein treated with different concentrations of ginger rhizome extract and controls

Time point	Treatment				
	NC	PC	GR200	GR400	GR800
FO	197.70±0.29 ^a	197.70±0.29 ^a	197.70±0.29 ^a	197.70±0.29 ^a	197.70±0.29 ^a
T0	197.65±0.09 ^a	196.99±0.69 ^a	197.22±0.22 ^a	197.23±0.23 ^a	197.71±0.13 ^a
Day 1	200.44±0.24 ^a	199.37±0.54 ^{bc}	200.38±0.23 ^{ab}	198.81±0.29 ^{cd}	197.88±0.56 ^d
Day 3	203.83±0.50 ^a	201.42±0.30 ^b	203.86±0.26 ^a	199.72±0.39 ^c	198.11±0.32 ^d
Day 5	213.38±0.43 ^a	207.31±0.39 ^b	213.78±0.74 ^a	202.86±0.40 ^c	198.81±0.24 ^d

Note: Values are mean values ±SD. Means in the same row that do not share a superscript letter differ significantly ($p < 0.05$). NC: Negative control (palm olein with no added antioxidant); PC: Positive control (palm olein with 200 ppm BHT); GR200, GR400, GR800: palm olein with 200ppm, 400ppm and 800ppm ginger rhizome extract, respectively; FO: Fresh oil (palm olein with no added antioxidant); T0: palm olein with added antioxidants, immediately after preparation

Table 7: p-AV levels during accelerated oxidation of palm olein treated with different concentrations of ginger rhizome extract and controls

Timepoint	Treatment				
	NC	PC	GR200	GR400	GR800
FO	0.79±0.02 ^a	0.79±0.02 ^a	0.79±0.02 ^a	0.79±0.02 ^a	0.79±0.02 ^a
T0	0.83±0.02 ^a	0.84±0.02 ^a	0.82±0.04 ^a	0.83±0.05 ^a	0.83±0.32 ^a
Day 1	5.36±0.02 ^a	2.86±0.02 ^d	3.84±0.08 ^b	3.73±0.03 ^{bc}	3.65±0.06 ^c
Day 3	11.40±0.04 ^a	7.56±0.03 ^e	11.01±0.03 ^b	10.21±0.04 ^d	10.81±0.03 ^c
Day 5	16.60±0.05 ^a	11.98±0.04 ^e	16.07±0.05 ^b	13.04±0.04 ^d	13.95±0.07 ^c

Note: Values are mean values ±SD. Means in the same row that do not share a superscript letter differ significantly ($p < 0.05$). NC: Negative control (palm olein with no added antioxidant), PC: Positive control (palm olein with 200 ppm BHT); GR200, GR400, GR800: palm olein with 200ppm, 400ppm and 800ppm ginger rhizome extract, respectively; FO: Fresh oil (palm olein with no added antioxidant); T0: palm olein with added antioxidants, immediately after preparation

Table 8: Extinction coefficients K_{232} and K_{268} during accelerated oxidation of palm olein treated with different concentrations of ginger rhizome extract and controls

	Timepoint	Treatment				
		NC	PC	GR200	GR400	GR800
Extinction Coefficient K_{232}	FO	2.35±0.01 ^a	2.35±0.01 ^a	2.35±0.01 ^a	2.35±0.01 ^a	2.35±0.01 ^a
	T0	2.35±0.01 ^a	2.35±0.01 ^a	2.35±0.02 ^a	2.36±0.03 ^a	2.35±0.02 ^a
	Day 1	2.64±0.04 ^a	2.38±0.01 ^b	2.43±0.02 ^b	2.40±0.02 ^b	2.39±0.02 ^b
	Day 3	3.16±0.02 ^a	2.95±0.01 ^c	3.12±0.02 ^a	2.84±0.02 ^d	3.00±0.02 ^b
	Day 5	3.53±0.03 ^a	3.00±0.02 ^e	3.47±0.00 ^b	3.37±0.02 ^c	3.08±0.02 ^d
Extinction Coefficient K_{268}	FO	1.05±0.01 ^a	1.05±0.01 ^a	1.05±0.01 ^a	1.05±0.01 ^a	1.05±0.01 ^a
	T0	1.06±0.02 ^a	1.05±0.02 ^a	1.05±0.01 ^a	1.05±0.03 ^a	1.05±0.01 ^a
	Day 1	1.36±0.02 ^a	1.13±0.01 ^c	1.31±0.02 ^a	1.17±0.01 ^{bc}	1.19±0.02 ^b
	Day 3	1.97±0.02 ^a	1.50±0.02 ^{bc}	1.52±0.02 ^b	1.48±0.01 ^c	1.21±0.01 ^d
	Day 5	2.23±0.03 ^a	1.80±0.02 ^c	1.90±0.01 ^b	1.83±0.02 ^c	1.74±0.02 ^d

Note: Values are mean values ±SD. Means that do not share a superscript letter in the same row of each extinction coefficient are significantly ($p < 0.05$) different. NC: Negative control (palm olein with no added antioxidant), PC: Positive control (palm olein with 200 ppm BHT); GR200, GR400, GR800: palm olein with 200ppm, 400ppm and 800ppm of ginger rhizome extract, respectively; FO: Fresh oil (palm olein with no added antioxidant); T0: palm olein with added antioxidants, immediately after preparation



REFERENCES

1. **Zhao X, Xiang X, Huang J, Ma Y, Sun J and D Zhu** Studying the evaluation model of the nutritional quality of edible vegetable oil based on dietary nutrient reference intake. *ACS Omega*, 2021; **6(10)**: 6691–6698.
2. **Kedir WM, Geletu AK, Weldegirum GS and MF Sima** Antioxidant activity of selected plants extract for palm oil stability via accelerated and deep-frying study. *Heliyon*, 2023; **9(7)**.
3. **Blasi F and L Cossignani** An overview of natural extracts with antioxidant activity for the improvement of the oxidative stability and shelf life of edible oils. *Processes*, 2020; **8(8)**: 956.
4. **Machado M, Rodriguez-Alcala LM, Gomes AM and M Pintado** Vegetable oils oxidation: Mechanisms, consequences and protective strategies. *Food Reviews International*, 2023; **39(7)**: 4180-4197.
5. **Abdo EM, Shaltout OE and HM Mansour** Natural antioxidants from agro-wastes enhanced the oxidative stability of soybean oil during deep-frying. *LWT*, 2023; **173**: 114321.
6. **Rasool N, Saeed Z, Pervaiz M, Ali F, Younas U, Bashir R, Bukhari SM, Jelani S and R Sikandar** Evaluation of essential oil extracted from ginger, cinnamon and lemon for therapeutic and biological activities. *Biocatalysis and Agricultural Biotechnology*, 2022; **44**: 102470.
7. **Loungaing VD, Djikeng FT, Teboukeu GB, Njike HF, Kamsu GT and HM Womeni** Effect of ginger extracts on palm olein quality during frying and impact of fried oils on some biological parameters of albino Wistar rats. *Journal of Food Research*, 2022; **11(3)**: 22–35.
8. **Prasad W, Wani AD, Khamrui K, Hussain SA and Y Khetra** Green solvents, potential alternatives for petroleum-based products in food processing industries. *Cleaner Chemical Engineering*, 2022; **3**:100052.
9. **Samudin MIZ, Aziz MYA and Y Nurhayati** Total Phenolic Content and Antioxidant Activity of *Passiflora edulis* Extract. *Journal of Agrobiotechnology*, 2022; **13(2)**: 1-9.
10. **Cisneros M, Canazza E, Mihaylova D and A Lante** The effectiveness of extracts of spent grape pomaces in improving the oxidative stability of grapeseed oil. *Applied Sciences*, 2024; **14(22)**: 10184.



11. **Djikeng FT, Womeni HM, Karuna MSL, Tiencheu B, Achidi AU, Linder M and RBN Prasad** Preservative effect of ginger root (*Zingiber officinale* R.) extract in refined palm olein subjected to accelerated thermal oxidation. *Journal of Food Quality*, 2022; **1**: 3388201.
12. **Alhakmani F, Khan SA and A Ahmad** Determination of total phenol, in-vitro antioxidant and anti-inflammatory activity of seeds and fruits of *Zizyphus spina-christi* grown in Oman. *Asian Pacific Journal of Tropical Biomedicine*, 2014; **4**: S656-S660.
13. **Akullo JO, Kiage-Mokua BN, Nakimbugwe D and J Kinyuru** Phytochemical profile and antioxidant activity of various solvent extracts of two varieties of ginger and garlic. *Heliyon*, 2023; **9(8)**.
14. **Moga DK, Adipo N, Matu EN and PG Kirira** Antioxidant and antiproliferative activity of *Azadirachta indica* A. Juss Extracts against cancer cell lines: An experimental study. *African Journal of Health Sciences*, 2021; **34(5)**: 650-656.
15. **Jadhav HB, Gogate PR, Waghmare JT and US Annapure** Comparative assessment of thermo-oxidative stability of palm oil designer lipid and palm oil blends as frying medium. *Applied Food Research*, 2022; **2(1)**: 100039.
16. **Hasan MS, Jahan R, Alam MA, Khatun M and SM Al-Reza** Study on physicochemical properties of edible oils available in Bangladeshi local market. *Archives of Current Research International*, 2016; **6(1)**: 1-6.
17. **Wazed M, Yasmin S, Basak P, Hossain A, Rahman MM, Hasan MR, Khair MM and M Khatun** Evaluation of physicochemical parameters of edible oils at room temperature and after heating at high temperature. *Food Res*, 2023; **7(4)**: 91–100.
18. **Patil RS, Waghmare J and U Annapure** Comparative assessment of the frying performance of palm olein and sunflower oil during deep-fat frying of Indian battered food products. *Journal of Agriculture and Food Research*, 2023; **14**: 100778.
19. **Sharanke K and S Sivakanthan** Comparative study on stability of coconut oil, sunflower oil and palm oil during continuous deep frying. *Ceylon Journal of Science*, 2022; **51(4)**.

20. **Ramroudi F, Yasini Ardakani SA, Dehghani-Tafti A and E Khalili Sadrabad** Investigation of the physicochemical properties of vegetable oils blended with sesame oil and their oxidative stability during frying. *International Journal of Food Science*, 2022; **1**: 3165512.
21. **Al-Areer NW, Al Azzam KM, Al Omari RH, Al-Deeb I, Bekbayeva L and ES Negim** Quantitative analysis of total phenolic and flavonoid compounds in different extracts from ginger plant (*Zingiber officinale*) and evaluation of their anticancer effect against colorectal cancer cell lines. *Pharmacia*, 2023; **70(4)**: 905-919.
22. **Spyrou A, Batista MGF, Corazza ML, Papadaki M and M Antonopoulou** Extraction of High Value Products from *Zingiber officinale* Roscoe (Ginger) and Utilization of Residual Biomass. *Molecules*, 2024; **29(4)**: 871.
23. **Nofita SD, Ngibad K and AF Rodli** Determination of percentage yield and total phenolic content of ethanol extract from purple passion (*Passiflora edulis* f. *edulis* Sims) fruit peel. *Jurnal Pijar Mipa*, 2022; **17(3)**: 309–313.
24. **Rangani SC and KKDS Ranaweera** Incorporation of natural antioxidants extracted from strawberry, cinnamon, beetroot, and ginger into virgin coconut oil for expansion of its shelf life. *Applied Food Research*, 2023; **3(2)**: 100325.
25. **Haroen U, Syafwan S, Kurniawan K and A Budiansyah** Determination of total phenolics, flavonoids, and testing of antioxidant and antibacterial activities of red ginger (*Zingiber officinale* var. *Rubrum*). *Journal of Advanced Veterinary and Animal Research*, 2024; **11(1)**: 114-124.
26. **Ezez D and M Tefera** Effects of solvents on total phenolic content and antioxidant activity of ginger extracts. *Journal of Chemistry*, 2021; **(1)**: 6635199.
27. **Jorge-Montalvo P, Vilchez-Perales C and L Visitación-Figueroa** Valorization of *Zingiber officinale* Roscoe postharvest residues as byproducts with antioxidant capacity. *Heliyon*, 2023; **9(8)**: e19137-e19137.
28. **Tsouko E, Alexandri M, Fernandes KV, Freire DMG, Mallouchos A and AA Koutinas** Extraction of phenolic compounds from palm oil processing residues and their application as antioxidants. *Food Technology and Biotechnology*, 2019; **57(1)**: 29.



29. **Pérez M, Dominguez-López I and RM Lamuela-Raventós** The chemistry behind the folin–ciocalteu method for estimating (poly) phenol content in food: Total phenolic intake in a mediterranean dietary pattern. *Journal of agricultural and food chemistry*, 2023; **71(46)**: 17543-17553.
30. **Ningsih IY, Faradisa H, Cahyani MD, Rosyidi VA and MA Hidayat** The formulation of ginger oil nanoemulsions of three varieties of ginger (*Zingiber officinale* Rosc.) as natural antioxidant. *J. Res. Pharm. (Online)*, 2020; **24**: 914-924.
31. **Vedashree M, Asha MR, Roopavati C and MM Naidu** Characterization of volatile components from ginger plant at maturity and its value addition to ice cream. *Journal of food science and technology*, 2020; **57(9)**: 3371–3380.
32. **Yusufali Z, Follett P, Wall M and X Sun** Physiochemical and Sensory Properties of a Turmeric, Ginger, and Pineapple Functional Beverage with Effects of Pulp Content. *Foods*, 2024; **13(5)**: 718.
33. **Djikeng FT, Ndikum BS, Tincho BM, Zemoh Sylvia Ninying VT and HM Womeni** Effect of turmeric root extract on the oxidative stability of palm oil, African walnut oil and their 50: 50 and 60: 40 blends during accelerated storage. *Food Biomacromolecules*, 2025; **2(1)**: 106—121.
34. **Ali S, Chatha SAS, Ali Q, Hussain AI, Hussain SM and R Perveen** Oxidative stability of cooking oil blend stabilized with leaf extract of *Eucalyptus citriodora*. *International Journal of Food Properties*, 2016; **19(7)**: 1556-1565.
35. **Wu G, Han S, Zhang Y, Liu T, Karrar E, Jin Q, Zhang H and X Wang** Effect of phenolic extracts from *Camellia oleifera* seed cake on the formation of polar compounds, core aldehydes, and monoepoxy oleic acids during deep-fat frying. *Food Chemistry*, 2022; **372**: 131143.
36. **Nowak M, Tryniszewski W, Sarniak A, Wlodarczyk A, Nowak PJ and D Nowak** Concentration Dependence of Anti- and Pro-Oxidant Activity of Polyphenols as Evaluated with a Light-Emitting Fe²⁺-Egta-H₂O₂ System. *Molecules*, 2022; **27(11)**: 3453.



37. **Ahmed MN, Abourat K, Gagour J, Sakar EH, Majourhat K and S Gharby** Saffron (*Crocus sativus* L.) stigmas as a potential natural additive to improve oxidative stability attributes of sunflower (*Helianthus annuus* L.) oil stored under different conditions. *Grain & Oil Science and Technology*, 2024; **7(3)**: 133–149.
38. **Esfahani ST, Zamindar N, Esmaeili Y and S Sharifian** Effect of initial quality of oil and thermal processing on oxidation indexes in canned tuna. *Applied Food Research*, 2024; **4(2)**: 100553.