CARPATHIAN JOURNAL OF FOOD SCIENCE AND TECHNOLOGY

journal homepage: **http://chimie-biologie.ubm.ro/carpathian_journal/index.html**

OPEN ACCESS

CC BY SA

Research article

EFFECT OF ENDOGENOUS ANTIOXIDANTS OF GOOSEBERRY (*PHYLLANTHUS EMBLICA L.*) SEEDS ON THE FRYING STABILITY OF SUNFLOWER OIL

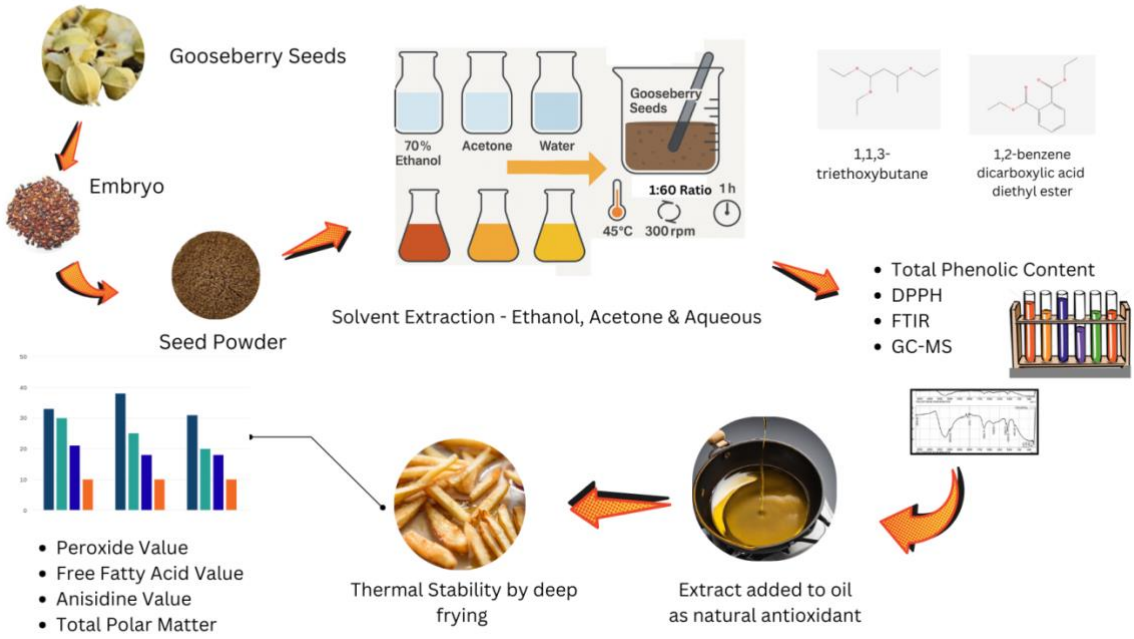
Thanushri Jonnakatla Saravanaguptha[1], Hrithickroshan Ayyanar Gangatharan[1], Sridhar Shanmugasundaram[1], Kirthika Suresh[1]✉

[1] Department of Food Technology, Rajalakshmi Engineering College, Chennai, Tamilnadu, India
✉Corresponding author: Kirthika Suresh. 0009-0000-3319-8699 E-mail: suresh.kirthika1@gmail.com
https://doi.org/10.34302/crpjfst/WIOU1754

Article history:
Received:
September 29th 2025
Accepted:
July 31th 2026
Published:
November 23th 2026

Keywords
Phyllanthus emblica seeds,
Sunflower oil;
Frying stability;
GC-MS analysi;
Total polar matter.

Abstract
Frying is an important food processing operation and the intense heat generated during frying leads to thermal oxidation of lipids with the formation of harmful oxidation products. Refined oil processing industries rely on synthetic antioxidants such as butylated hydroxytoluene (BHT) which further raises safety and consumer acceptance concerns. To address this issue, the present study explores the antioxidant potential of Phyllanthus emblica L. (gooseberry) seeds and its effectiveness in suppressing the progression of lipid oxidation and enhancing the frying stability of sunflower oil. The antioxidant compounds present in the gooseberry seeds were extracted using three different solvents such as ethanol, acetone, and water of which the ethanolic extract exhibited the highest radical scavenging activity (84.21%) with a total phenolic content of 362.33 mg Gallic acid equivalent GAE/g extract. FTIR and GC-MS analysis identified the presence of phenolic antioxidant compounds such as carvacrol, ethyl homovanillate, 2,6-dihydroxybenzoic acid and fatty acid esters including 1,1,3-triethoxybutane, 1,2-benzenedicarboxylic acid and hexadecenoic acid. The dried ethanolic extract of the gooseberry seeds were incorporated into sunflower oil at concentrations of 500, 1000 and 2000 ppm and subjected to frying treatment at 200°C in three cycles. The frying stability of the oil samples were evaluated using peroxide value (PV), free fatty acid value (FFAV), p-anisidine value (p-AV) and total polar materials (TPM). It was observed that addition of 2000ppm extract significantly reduced PV (25.6%), FFAV (65.62%), p-AV (59.1%) and TPM (63.98%) compared to control with no added antioxidant. The results are also comparable with 200ppm BHT. These findings suggest that endogenous antioxidants of gooseberry seeds can be an effective natural alternative to synthetic antioxidants to improve the frying stability of edible oils.



Graphical abstract

Visual summary of the antioxidant activity of gooseberry seed phenolic compounds in suppressing lipid oxidation of sunflower oil during frying

1.Introduction

Edible oils and fats (95-98% triacylglycerol) are a very important part of human diet as they play a crucial role in making the food more palatable while also acting as a solvent for the fat soluble vitamins. Frying with fat or oil is one of the oldest and most popular food preparation methods the food is cooked by immersion in hot oil (Asokapandian et al., 2020). Deep-fat frying at elevated temperatures and moisture levels can result in decomposition products such as epoxides, polar dimmers, oxidized triglycerides, trans fatty acids and acrylamide, which can have negative nutritional and health consequences. These compounds accumulate in frying oils, causing degradation, entering the diet, and affecting public health. Highly oxidized oils can also produce carcinogenic polycyclic aromatic hydrocarbons (Dangal et al., 2024). These toxic degradation compounds have been linked to serious health disorders including heart failure, hypertension, cancer, Parkinson's and Alzheimer's disease (Ganesan & Xu, 2020). Frying oil quality and the frying cycles are critical for food quality and shelf life (Ujong et al., 2023). Sunflower oil, a significant global oilseed crop, contains high levels of oleic (14–40%) and linoleic acids (48–74%), which are beneficial but prone to oxidation. This oxidation, exacerbated by light, heat, trace metals, and oxygen, affects oil quality and safety. Antioxidants, both synthetic and natural, are employed to inhibit lipid oxidation. The oxidative and frying stability of lipids to a great extent depends upon the presence of natural/synthetic antioxidants (Kamalesh et al., 2025; Shahidi & Zhong, 2015) . Synthetic antioxidants such as butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), and propyl gallate, have been extensively utilized in food industries to inhibit lipid oxidation and preserve the freshness of food products but the toxicological and carcinogenic effects of synthetic antioxidants has increased the demand for natural antioxidants (Xu et al., 2021). Recent research findings show that polar phenolic compounds exhibit high antioxidant activity and frying stability compared to non-polar phenolics. Polar rosmarinic acid in synergy with carnosic acid from rosemary extract exhibited higher antioxidative efficacy than tert-butyl hydroquinone in soybean oil at 180 °C (Li et al.,

2021) . Incorporation of gallic acid at 200 ppm in corn oil at 180 °C for 6 cycles improved thermal stability more effectively than BHA or propyl gallate at the same concentration. Tea seed oil polyphenols such as epicatechin (EC) and epigallocatechin gallate (EGCG) at 300 ppm significantly reduced total polar materials and oxidative products in soybean oil during frying at 170 °C . (Ali & Chew, 2023). Potato peel extract containing phenolics such as gallic, caffeic and ferulic and chlorogenic acids has demonstrated significant antioxidant activity at 3200ppm in mainintaing the stability of sunflower oil during storage upto 60 days (A. Saeed et al., 2024) . *Phyllanthus emblica L.* (Indian Gooseberry) popularly known as amla, a plant belonging to the family Euphorbiaceae, is widely found in most tropical and subtropical countries. *Phyllanthus* is a relatively large genus with 10–11 subgenera and roughly 550–750 species. It is native to equatorial southeast Asia and can be found between 150 and 1,400 meters above sea level in mixed forests in tropical and subtropical areas (Hussain et al., 2021). Traditionally, Indian gooseberries/amla has been processed into a variety of products such as RTS beverages, amla jam, amla powder and candied amla (Sivakumar & Nallakurumban, 2020). In Ayurvedic medicine, amla is recognized as a rasayana and has been utilized since time immemorial to treat and prevent a wide range of ailments. Various parts of the plant, including the fruit, leaves, roots, bark, and flowers are incorporated into traditional polyherbal formulations (Talreja et al., 2021). Gooseberry seeds, often considered a by- product during amla processing, has gained prominence as a notable source of natural antioxidants because of its rich repository of bioactive compounds. Studies indicate that the gooseberry seeds have more antioxidant activity than the fruit. The polyphenolic compounds present in the seeds contribute to its antioxidant activity (Kaur et al., 2021; Nadheesha et al., 2011). Compounds with antioxidants such as gallic acid, catechol, ellagic acid, phloroglucinol, pyrogallol, trigalloylglucose, indol acetic acid (IAA), vitamin C, ß-carotene, superoxide dismutase enzyme have been reported to be present in gooseberry seeds (Prananda et al., 2023). While there are reported research on the antioxidant activity of these seeds, there exists a gap on how this potential can be valorised as a natural additive to improve the thermal stability of edible oils. Therefore, this study aims to evaluate and compare the phenolic content and antioxidant activity of *Phyllanthus emblica L.* seeds extracted using three different solvents - water, acetone and ethanol. The antioxidant efficacy was assessed by performing lipid peroxidation assays such as free fatty acid value, peroxide value, p- anisidine value and total polar matter in sunflower oil incorporated with the extracts subjected to successive frying treatments and the results were compared with regulatory upper limit of 200ppm BHT added oil which is a standard industrial benchmark in edible oil processing industry, thus providing insights into the potential of gooseberry seed extracts as natural alternative to synthetic antioxidants in edible oils.

2. Materials And Methods

2.1. Materials

Phyllanthus emblica L. (Indian Gooseberry) was procured from a local market in Koyambedu, Chennai. Refined sunflower oil with no added antioxidants was sourced from Mehrotra Consumer Products Pvt Ltd, India. Butylated hydroxyanisole (BHA) was procured from Camlin Fine Sciences Pvt Ltd (India). 1, 1-diphenyl-2-picrylhydrazyl (DPPH) was procured from Sigma-Aldrich. Solvents and other chemicals used in this study are analytical grade and procured from Merck (Germany).

2.2. Drying of *Phyllanthus emblica L.* seeds

Fresh gooseberries were pulped to separate the seeds. Seeds were removed from the seed coat by crushing with a mortar and pestle. The seeds were subjected to drying in a tray dryer (Digiqual systems) at 55°C until constant weight was obtained (Kaur et al., 2021). Weight was recorded every 30 minutes. Drying temperature strongly influences the antioxidant activity of the seeds. Drying at 55°C ensures better

retention of phytochemical compounds with minimal loss due to degradation (Suresh et al., 2025). Graph was plotted between drying time and the weight of the seeds to obtain a drying curve. The moisture content (dry basis) of the seeds and the drying rate were calculated using the formula:

$$M_d = \frac{W_i - W_f}{W_d} \quad (1)$$

$$\text{Drying rate} = \frac{M_t - M_{t+dt}}{\text{dt}} \quad (2)$$

where M_d - moisture content on dry basis in kg water/kg dry matter, W_i, W_f and W_d are initial, final and dry matter weights in kg respectively. Drying rate is expressed as kg water/kg dry matter/hr, M_t is moisture content at time t and dt refers to the time interval in hours. The dried seeds were size reduced by grinding into a fine powder using electric grinder, passed through a 40 mesh screen and was stored in high density polyethylene air tight container at 4°C for further use.

2.3. Extraction of *Phyllanthus emblica L.* seeds

Extraction efficiency, phytochemical yield and antioxidant activity depends predominantly on the solvent used as plant extracts contain a mixture of bioactive compounds of variable polarity and different functional groups. While aqueous ethanol can extract polar and moderately polar phytochemicals, acetone extracts high molecular weight phenolics, hydrolysable and condensed tannins and conventional aqueous solvent recovers highly polar phenolic compounds (Ghaffar & Perveen, 2025). Therefore, 70% ethanol, acetone and water were employed for the extraction of gooseberry seeds. The dried seed powder was combined with the respective solvent in 1:60 ratios and extracted by conventional solid-liquid extraction where the mixture was agitated at 300rpm for 1 hour in a magnetic stirrer at a moderate temperature of 45°C to avoid degradation of the phenolic compounds. Then the mixture was filtered using Whattman No.1 filter paper and centrifuged at 2000 rpm for 10 minutes. The supernatant was collected and the solvents were evaporated using a rotary vacuum evaporator. The dry weight was recorded to calculate the extraction yield (w/w – yield of dry extract in g/total powdered dry material taken in g). The dried extract was re-suspended in its respective solvents at 2000ppm (0.02g/ml) concentration and were subjected to further analysis Multiple extraction batches were performed to obtain sufficient extract mass (Chemat et al., 2019; Poltanov et al., 2009).

2.4. Qualitative Phytochemical Analysis

Phytochemical screening of the gooseberry seed extracts (GSE) was performed to identify the presence of phenolic compounds according to the method described by Shaikh & Patil, 2020

a) Alkaloids: 3 mL of GSE was mixed with a few drops of iodine. Appearance of blue colour, which disappears upon heating and reappears upon cooling, indicates a positive reaction.
b) Flavonoids: 1 mL of GSE was mixed with 1 mL of concentrated H_2SO_4. Appearance of orange colour, indicates a positive reaction.
c) Phenolic Compounds: 2 mL of GSE was mixed with 1 mL of 2N NaOH and heated at 100°C for 5 minutes. Appearance of a bluish-green colour confirms the presence of phenolic compounds.
d) Saponins: 0.5 mL of GSE was shaken well with 2 mL of water. Foam formation indicates a positive reaction.
e) Quinones: 1 mL of GSE was mixed with 1 mL of concentrated HCl. Appearance of green colour indicates a positive reaction.
f) Phlobatannins: 1 mL of GSE was mixed with 1 mL of 1% HCl. Appearance of a red precipitate indicates a positive reaction.
g) Anthraquinones: 1 mL of GSE was mixed with few drops of 10% NH_3 solution. Appearance of a pink precipitate indicates a positive reaction.
h) Tannins: 1 mL of GSE was mixed with 2 mL of 5% $FeCl_3$ solution. Appearance of greenish-black colour, indicates a positive reaction.

2.5.Determination of Total Phenolic Content

Total phenolic content (TPC) of the GSE was performed by Folin–Ciocalteu method as per (Hagos et al., 2023) with some modifications. 0.5 ml of seed extract obtained using different solvents was added to 2.5 ml of 10% Folin–Ciocalteu Reagent and 2 ml of 6% Na_2CO_3. The mixture was incubated under dark for 20 minutes. The absorbance was recorded at 765nm in UV spectrophotometer (Systronics AU 2703 Double Beam UV-VIS Spectrophotometer). The TPC of the extracts were quantified by employing a calibration curve that was obtained using gallic acid standards of known concentration ($R^2 = 0.9731$).

2.6. DPPH Radical Scavenging Activity

The antioxidant activity (radical scavenging activity) of the GSE was determined by the 2,2-diphenyl-1- picryl hydrazyl free radical (DPPH) scavenging assay as per (Saeed et al., 2022). 1 ml of the seed extract was added to 1ml of 0.1 mmol/l DPPH reagent, vortexed for one minute, incubated in the dark for 30 minutes and absorbance was measured at 520nm. Similarly, a blank was prepared using ethanol (control). Triplicate measurements were made. The % radical scavenging activity was calculated using the formula below.

$$\% \text{ Inhibition} = \frac{A_0 - A_1}{A_0} \times 100 \quad (3)$$

Where, A_0= Absorbance of control ; A_1 = Absorbance of sample

2.7. GC-MS (Gas chromatography-mass spectrometry) analysis of seed extract

The GC-MS analysis was performed for the GSE with highest TPC and antioxidant activity (DPPH) using a Shimadzu GCMS-QP 2010Plus gas chromatograph interfaced with a quadrupole mass spectrometer. The oven temperature was set from 50ºC to 280ºC at 10ºC/min and maintained for 2 minutes. Helium was used as a carrier gas at a flow rate of 1.0 mL per minute. The injector temperature was 250 ºC, the injection size was 1 µL, and the split ratio was 1:50. The interface and MS ion source were kept at 280ºC and 200ºC, respectively. Mass spectra were collected at 70eV with a scan range of 35-700 amu. Data was processed using GCMS solution software.The identification of compounds was based on comparison of their mass spectra with those of WILEY and NIST Libraries (Baeshen et al., 2023).

2.8. FTIR (Fourier Transform Infrared Spectroscopy)

The FTIR spectrum of the GSE was performed on a Shimadzu Prestige FT-IR spectrometer under attenuated total reflection (ATR) operation with a diamond crystal cell. The spectra were recorded (30 scans per sample) in the wavelength range of 4500–400 cm^{-1} at a resolution of 4 cm^{-1}. The analysis was conducted at room temperature (32°C) (Agatonovic-Kustrin et al., 2021).

2.9. Frying stability of sunflower oil with GSE

The solvent extract which exhibited the highest phenolic content and radical scavenging activity was incorporated in sunflower oil at concentrations of 500ppm, 1000 ppm and 2000 ppm (dry matter) to study its thermal stability. Sunflower oil with no synthetic antioxidants was preheated to 50°C. The dried seed extract was added to the oil and agitated for 2 hours in an orbital shaker at 200 rpm (Metzner Ungureanu et al., 2020). Butylated hydroxy toluene (BHT) 200ppm added oil sample was used as commercial control. Three sets of frying experiments were performed; GSE added oil, BHT added oil and control oil sample (with no antioxidants). To study the oil's frying stability, 150ml of the oil samples were heated to 180°C and sliced potatoes (6.0 x 0.2 x 0.2 cm) were fried for 5 minutes in 3 cycles. The samples were then tested for its free fatty acid, peroxide, anisidine value and total polar matter as per the AOCS, 1998 .

2.10. Peroxide Value

Peroxide Value (PV) is a measure of the primary oxidation products, primarily peroxides, produced by oxygen reacting with

unsaturated fatty acids. It is typically determined using a titration-based method and reported in milli-equivalents per kilogram of fat (Abdo et al., 2023). Refined, bleached, and deodorized oils typically have a PV below 1.0 meq/kg oil. 5g oil, 30 ml acetic acid-chloroform mixture, 0.5 ml KI were taken, 30 ml distilled water and starch indicator were added to the mixture. The solution was titrated against 0.01N sodium thiosulphate solution where, disappearance of blue colour indicates the endpoint (AOCS, 1998).

$$\text{Peroxide Value (meq/kg oil)} = \frac{\text{V x normality of sodium thiosulphate}}{\text{weight of sample taken(g)}} \text{X1000} \quad (4)$$

2.11. Free Fatty Acid Value

Free fatty acids (FFAs) produced by hydrolytic degradation is an important indicator of the rancidity of fat and oil (Abdo et al., 2023). To 50 ml ethanol, phenolphthalein indicator was added and titrated against 0.1N NaOH solution to neutralize the ethanol. To the neutralized ethanol, 10 ml oil sample was added and titrated against 0.1N NaOH solution. The appearance of pink colour marks the endpoint. FFA is calculated using the formula

$$\text{Free Fatty acid (\%oleic acid)} = \frac{\text{V(ml) x N x 28.2}}{\text{Wt of oil (g)}} \quad (5)$$

2.12. p-Anisidine value

p-Anisidine value (p-AV) represents the level of secondary oxidation products, mainly aldehydes and ketones, formed when oxygen reacts with the fatty acid chains in the oil (Chen et al., 2022). Two grams (w) of oil samples were dissolved in 25 mL of isooctane, and the absorbance (A_1) of the solution was measured at 350 nm against an isooctane blank. 5 mL aliquot of this solution, as well as 5 mL of isooctane (as a blank), was transferred to each of two 10 mL test tubes. To each tube, 1 mL of anisidine solution (0.25% g/v in glacial acetic acid) was added. After 10 minutes, the absorbance (A_2) was measured at 350 nm against an isooctane solution containing p-anisidine (AOCS, 1998). The p-AV was then calculated using formula (6)

$$\text{p-AV} = 25 \text{ X } \frac{1.2 \text{ X } (A_2 - A_1)}{w} \quad (6)$$

2.13. Total Polar Matter

Total Polar Matter (TPM) is a widely used method to evaluate the cumulative degradation of frying oils. TPM is a measure of compounds including oxidized monomers, dimerized and polymerized triacylglycerols, monoacylglycerols, diacylglycerols, free fatty acids, and other oil-soluble substances that are more polar than the original triacylglycerols (Kedir et al., 2023). A digital TPM Oil Tester (Testo 270 Resolution: 0.5%) was used to measure TPM in the oil sample (TPM).

2.14. Statistical Analysis

Each determination was performed in triplicate, and the results are presented as mean ± standard deviation (SD). Data analysis was conducted using analysis of variance (ANOVA) with Data Analysis Toolpak in Microsoft Excel. A p-value of ≤ 0.05 (5%) was deemed to indicate statistical significance.

3. Results And Discussion

3.1 Drying rate of gooseberry seeds

The weight loss profile and the change in moisture content with time of the gooseberry seeds are represented in Fig.1. The drying process reached equilibrium after 270 minutes and the initial moisture content (dry basis) was calculated to be 4.87% which decreased progressively during drying with an average drying rate of 0.0093 g water/min. (Fig 1). This suggests that moisture removal happens predominantly in the later stage (falling rate period) of drying. Similar drying mechanisms have been reported during the drying of ginkgo seeds (Boateng & Yang, 2021) and cumin seeds (Namjoo et al., 2023).

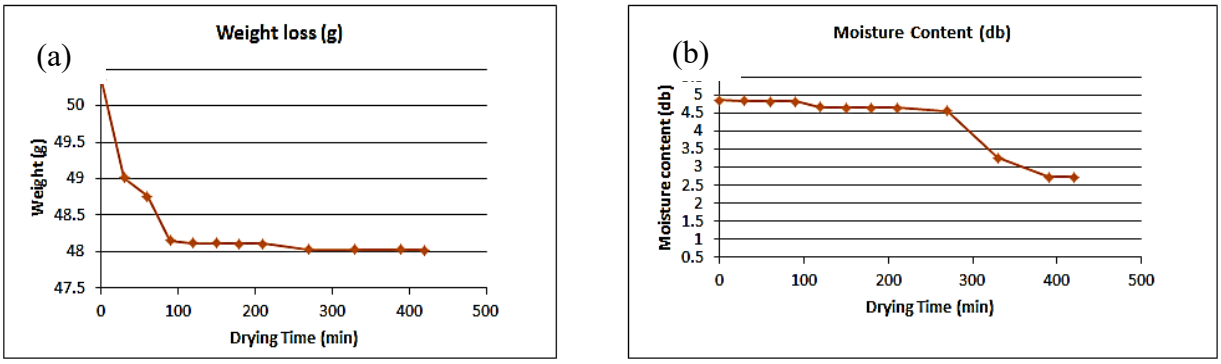


Figure 1. (a) Weight loss profile of the sample during drying as a function of drying time (b) Moisture content (dry basis) versus drying time graph of Phyllanthus emblica L. seeds

Table 1. Preliminary phytochemical screening of gooseberry seed extracts with different solvents

S.no.	Phytochemical Analysis	Ethanolic GSE	Acetone GSE	Aqueous GSE
1.	Flavonoids	+	+	+
2.	Phenolic compounds	+	+	+
3.	Saponins	+	+	+
4.	Quinones	+	+	+
5.	Phlobatannins	+	+	+
6.	Tannins	+	+	+
7.	Alkaloids	-	-	-
8.	Anthroquinones	-	-	-

Note: + indicates the presence and - indicates the absence of the specific phytochemical compound in the gooseberry seed extract

3.2. Qualitative Phytochemical Analysis

The results of phytochemical analysis are presented in Table 1. The qualitative analysis of phytochemicals in the samples suggests that GSE possess significant antioxidant properties. The presence of flavonoids, phenolic compounds, saponins, quinones, phlobatannins, and tannins indicates the potential ability of the extract to delay lipid oxidation on thermal treatment. The absence of alkaloids and anthraquinones does not necessarily imply a lack of antioxidant activity. Alkaloids and anthraquinones can possess antioxidant properties depending on their specific structures and functional groups (Wang et al., 2024). The presence of the aforementioned phytochemicals strongly suggests that the samples exhibit significant antioxidant activity.

3.3. Gooseberry seed extraction yield

Table 2 shows that the yield of aqueous, acetone, and ethanolic solvents varied significantly ($p < 0.05$), with ethanol producing the highest yield (31.4%) and water the lowest (23.12%). These variations in extraction yield are likely due to the miscibility and polarity of the antioxidants. 70% ethanol extract had higher yield compared to aqueous, indicating the presence antioxidant compounds of moderate polarity in gooseberry seeds, which are more soluble and miscible in aqueous ethanol leading to higher extraction efficiency. Lohvina et al.,

2021 has reported that 70% ethanol is the best solvent for maximum extraction of phenolic and antioxidant compounds in fenugreek seeds.

3.4. Total Phenolic Content (TPC)

Table 2 shows that the ethanolic extract exhibits the highest total phenolic content (TPC) compared to the acetone and aqueous extract. The results obtained are comparable to the results given by Jaiboonma et al., 2018. The aqueous extract had the lowest TPC, suggesting that water is not as effective as ethanol or acetone for extracting phenolic compounds from this particular sample. This suggests that 70% ethanol is a more effective solvent for extracting phenolic compounds from gooseberry seeds.

Table 2. Effect of extraction solvent on yield, total phenolic content, and antioxidant activity of gooseberry seed extract

Solvent	Yield (%)	TPC (mgGAE/g dry extract)	Radical scavenging activity%
Aqueous	23.12 ± 2.26	92.17 ± 4.57^{a}	69.5 ± 1.6^{a}
Acetone	26.5 ± 1.2	326.27 ± 5.50^{b}	76.95 ± 0.34^{b}
Ethanol	31.4 ± 2.3	362.33 ± 3.51^{b}	84.21 ± 0.16^{c}

Results are expressed as mean ± SD. Values within the same column sharing different superscripts denote that the difference is significant ($p < 0.05$); values within the same column sharing the same superscripts denote that the difference is not significant ($p > 0.05$)

3.5. DPPH Radical Scavenging Activity

DPPH radical scavenging activity is a simple and effective assay to express the hydrogen or electron donating capability of the extracts (Gulcin & Alwasel, 2023). From table 2 it is clear that the ethanolic extract has the highest radical scavenging activity (84.2%) which is 8.6% higher than that of acetone extract and 17.4% higher than aqueous extract. The lower radical scavenging activity of aqueous extract can be attributed to its lower phenolic content and the fewer reductant antioxidant compounds. Thus it can be concluded that the 70% ethanolic gooseberry seed extract is most suitable for incorporation in sunflower oil to improve its frying stability.

3.6. Gas Chromatography – Mass Spectrometry (GC-MS) of ethanolic extract

Five significant peaks were visible in the GC-MS chromatogram of the *Phyllanthus emblica L.* seed ethanolic extract (Fig.2). The main constituents of the extract were found to include fatty acid esters such as 1,1,3-triethoxybutane, 1,2-benzenedicarboxylic acid - diethyl ester, hexadecenoic acid-methyl ester, methyl 9-cis, 11-trans-octadecadienoate, and 9-octadecenoic acid-methyl ester and phenolic antioxidant compounds such as carvacrol, ethyl homovanillate, 2,6-dihydroxybenzoic acid. Similar compounds have been identified from the ethanolic extracts of certain medicinal plants such as *Moringa oleifera* (Vats & Gupta, 2017) and *Dendrophthoe falcata* (Beulah et al., 2018). The GC–MS profile confirms that *Phyllanthus emblica L.* seeds are a promising source of natural antioxidant compounds.

3.7. FTIR (Fourier Transform Infrared Spectroscopy)

The FTIR spectrum (Fig 2) has revealed different characteristic peak values with various functional groups present in the ethanolic extract. Hydrocarbons, alcohol, carbonyl and amines are the major compounds present in the extract. Other functional groups include C-Br stretch ($381.91 cm^{-1}$), N-H stretch ($395.41 cm^{-1}$), C-Cl stretch ($410.84\ cm^{-1}$), C-N

stretch (449.41cm^{-1}), C-H in plane bending vibration (867.97cm^{-1}), C-O stretch (1039.63cm^{-1}), C-C stretch (1082.07cm^{-1}), C-H deformation vibration(1392.61 cm^{-1}), C-C stretch (1633.71cm^{-1}), Alkyne C-H stretch (2002.11cm^{-1}), Alkyne C-H stretch (2974.23cm^{-1}), O-H stretch (4679.31cm^{-1}). 1633 cm^{-1}- C=C stretching indicates the presence of aromatic ring compounds like flavonoids known for their antioxidant properties. Similarly 1320-1020 cm^{-1} - C-O and C-N stretching are associated with alcohols, ethers, amines and ethers indicative of glycosides with antioxidant properties (Johnson et al., 2020).

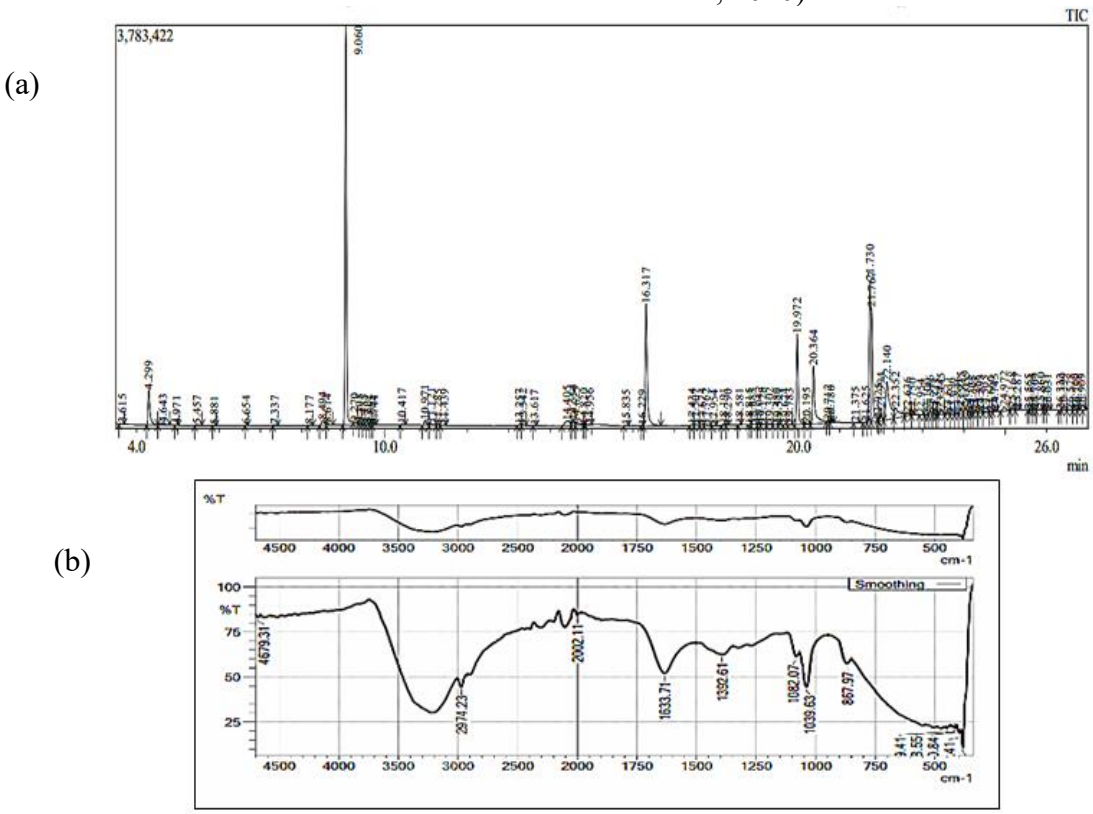


Figure 2. (a) GC–MS total ion chromatogram of the GSE showing major phytochemical constituents (b) FTIR spectrum of the GSE indicating major functional groups

3.8. Free Fatty Acid (FFA)

FFA strongly correlates to the extent of primary oxidation of oil sample From fig.3 it is evident that the increase in FFA is more pronounced in the control group, implying that the lack of antioxidants causes significant degradation over multiple heating cycles. As the GSE concentration increases (from 500 ppm to 2000 ppm), the increase in FFA content across heating cycles becomes more gradual, indicating that higher GSE concentrations are more effective at preventing the formation of free fatty acids. Thus it is evident that 2000 ppm GSE has reduced the FFA production in sunflower oil by 65.62% and it can act as a reliable source of natural antioxidants with acceptable thermal stability comparable to 200ppm of synthetic antioxidant BHT that shows 70% reduction in FFA. These results are comparable to a recent study where the incorporation of garlic (0.1 g/mL of oil) significantly reduced the acidity of sunflower oil compared with the control (Erickson et al., 2023).

3.9. Peroxide Value (PV)

The Codex Alimentarius Commision has established a maximum peroxide value limit of 10 meqO2/kg oil for frying oil (Say et al., 2024). Fig.3 depicts that with every cycle, the control sample exhibits increasing peroxide values,

indicating higher lipid oxidation. When antioxidants are added, peroxide values are significantly reduced. In the first, second and third cycles, GSE at 2000 ppm reduces the peroxide value by 37.0%, 29.8%, and 25.6%, respectively, in comparison to the control. Similar observation has been made by where 0.5% Moringa (*Moringa oleifera Lam*.) and Jujube (*Ziziphus Lotus Linn*.) leaf extracts retards the oxidation rate as evidenced by lower peroxide values compared to control. (Dhibi et al., 2022).

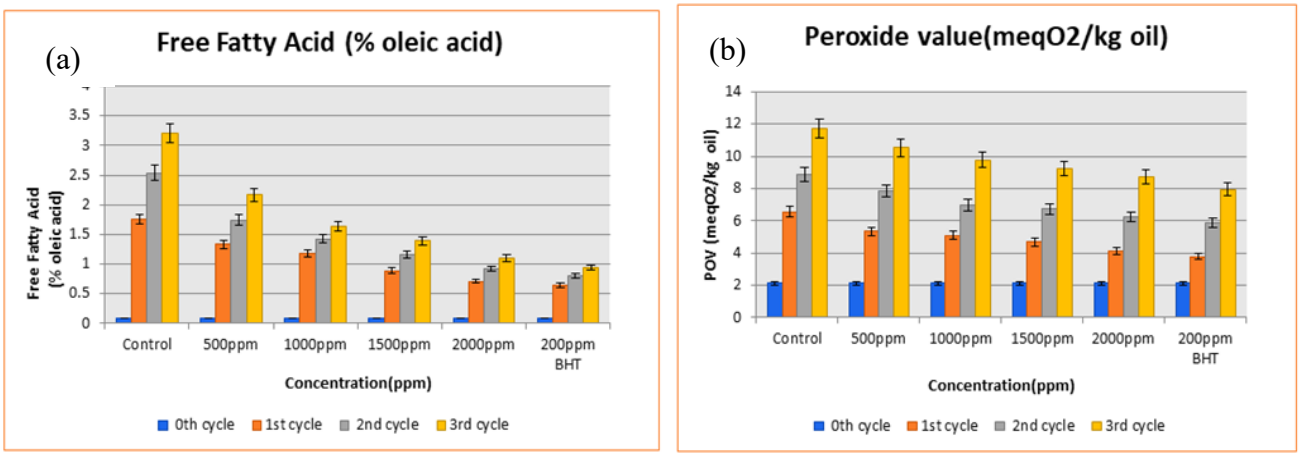


Figure.3 Impact of frying treatment in three cycles at 200°C on (a) FFA and (b) PV of oil samples supplemented with GSE in comparison with BHT and control with no added antioxidants. Results are calculated as the mean of three replicate measurements ± S.D

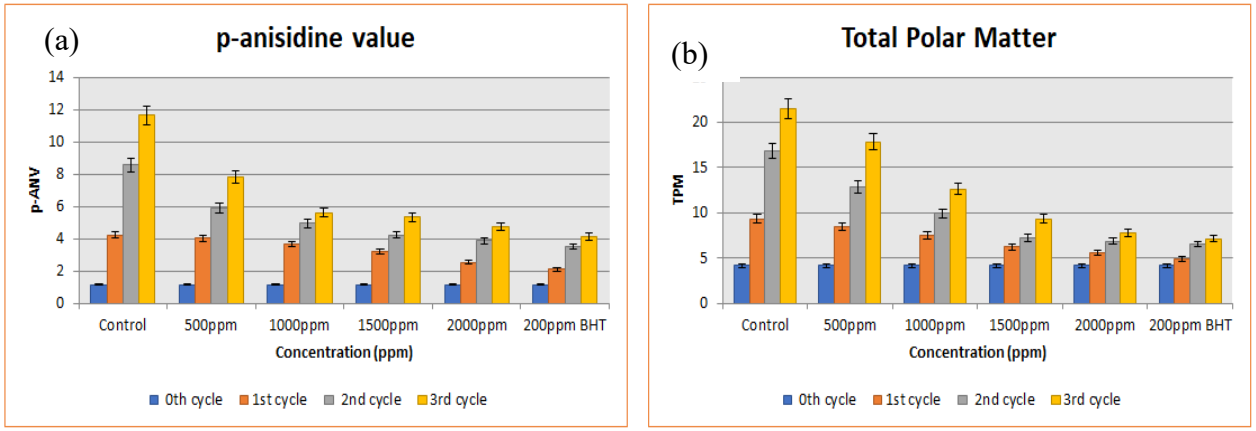


Figure 4. Impact of frying treatment in three cycles at 200°C on (a) p-AV and (b) TPM of oil samples supplemented with GSE in comparison with BHT and control with no added antioxidants. Results are calculated as the mean of three replicate measurements ± S.D

3.10. p- Anisidine value

As an index of secondary oxidation, p-anisidine values (Fig 4) of the control samples increases with each frying cycle, indicating an accumulation of aldehydes brought on by oil oxidation. Gooseberry seed antioxidants considerably lowered p-anisidine values; higher concentrations were more effective in this regard. In comparison to the control in the first, second, and third cycles, the natural antioxidant at 2000 ppm reduces p-anisidine values by 40.0%, 54.7%, and 59.1%, respectively. The results were comparable to that of BHT with 64.5% decrease in p-anisidine value compared

to the control sample. This strongly suggests that *Phyllanthus emblica L*. seed ethanolic extract at 2000 ppm concentration is most effective in inhibiting secondary lipid oxidation during repeated frying Similar results have been reported where the addition of rosemary ethanolic extract (0.12 g/kg) resulted in the lowest p-anisidine values (1.7–87.5), indicating effective suppression of secondary lipid oxidation (Guo et al., 2016).

3.11. Total polar matter

Total polar matter is an important and reliable method to measure the oil degradation subjected to frying treatment. When the critical limit of 27% is reached, the frying oil must be discarded As shown in Fig. 4, oil degradation decreased progressively with increasing concentrations of gooseberry seed ethanolic extract (GSE), attributable to the inhibition of oxidative and polymerization reactions during frying. Among the tested levels, 2000 ppm GSE was the most effective, resulting in a 63.98% lower degradation value than the control after the third frying cycle. Similar improvement in frying oil stability have been reported with 0.14% ethanolic pomegranate peel extract during deep frying of French fries (Qi et al., 2022).

4. Conclusion

Deep-fat frying accelerates oil oxidation, while limitations of synthetic antioxidants highlight the need for safe, natural antioxidants. In this context, the present study clearly reflects that incorporation of 2000 ppm gooseberry seed dry ethanolic extract improves the frying stability of sunflower oil in terms of free fatty acid value, peroxide value, p- anisidine value and total polar matter and the results were comparable to those of 200 ppm BHT treated sunflower oil. These findings suggest that endogenous antioxidants from *Phyllanthus emblica L* seeds have promising potential as natural antioxidants in sunflower oil, and may also have the same effect on other edible oils, potentially extending its shelf life and preserving its quality. Future studies may incorporate fatty acid profiling and specific oxidation markers to further elucidate the role of specific bioactive compounds in inhibiting thermal degradation of lipids during frying. Additionally, investigations into the storage stability of extract-incorporated oils and application of encapsulation techniques may further enhance the antioxidant activity of the extract and practical applicability of *P. emblica* seed extracts in food systems.

5. References

Abdo, E. M., Shaltout, O. E., & Mansour, H. M. (2023). Natural antioxidants from agro-wastes enhanced the oxidative stability of soybean oil during deep-frying. *Lwt*, *173*, 114321.

Agatonovic-Kustrin, S., Balyklova, K. S., Gegechkori, V., & Morton, D. W. (2021). HPTLC and ATR/FTIR characterization of antioxidants in different rosemary extracts. *Molecules*, *26*(19), 6064.

Ali, M. A., & Chew, S. C. (2023). Efficacy of exogenous natural antioxidants in stability of polyunsaturated oils under frying temperature. *Journal of Food Measurement and Characterization*, *17*(1), 408–429.

AOCS, O. (1998). Methods and recommended practices of the American Oil Chemists' Society. *American Oil Chemists' Society, Champaign, IL, USA*.

Asokapandian, S., Swamy, G. J., & Hajjul, H. (2020). Deep fat frying of foods: A critical review on process and product parameters. *Critical Reviews in Food Science and Nutrition*, *60*(20), 3400–3413.

Baeshen, N. A., Almulaiky, Y. Q., Afifi, M., Al-Farga, A., Ali, H. A., Baeshen, N. N., Abomughaid, M. M., Abdelazim, A. M., & Baeshen, M. N. (2023). GC-MS analysis of bioactive compounds extracted from plant Rhazya stricta using various solvents. *Plants*, *12*(4), 960.

Beulah, G. G., Soris, P. T., & Mohan, V. (2018). GC-MS determination of bioactive compounds of Dendrophthoe falcata (LF) Ettingsh: An epiphytic plant. *Int. J. Health Sci. Res*, *8*, 261–269.

Boateng, I. D., & Yang, X. (2021). Osmotic, osmovacuum, sonication, and osmosonication pretreatment on the infrared drying of Ginkgo seed slices: Mass transfer, mathematical modeling, drying, and rehydration kinetics and energy consumption. *Journal of Food Science*, *86*(10), 4577–4593.

Chemat, F., Abert Vian, M., Ravi, H. K., Khadhraoui, B., Hilali, S., Perino, S., & Fabiano Tixier, A.-S. (2019). Review of alternative solvents for green extraction of food and natural products: Panorama, principles, applications and prospects. *Molecules*, *24*(16), 3007.

Chen, J., Zhang, L., Li, Q., Gao, Y., & Yu, X. (2022). Utilization of Diaphragma juglandis extract as a natural antioxidant for improving the oxidative stability of soybean oil during deep frying. *Food Chemistry: X*, *14*, 100359.

Dangal, A., Tahergorabi, R., Acharya, D. R., Timsina, P., Rai, K., Dahal, S., Acharya, P., & Giuffrè, A. M. (2024). Review on deep-fat fried foods: Physical and chemical attributes, and consequences of high consumption. *European Food Research and Technology*, *250*(6), 1537–1550.

Dhibi, M., Amri, Z., Bhouri, A. M., Hammami, S., & Hammami, M. (2022). Comparative study of the phenolic profile and antioxidant activities of Moringa (Moringa oleifera Lam.) and Jujube (Ziziphus Lotus Linn.) leaf extracts and their protective effects in frying stability of corn oil. *Measurement: Food*, *7*, 100045.

Erickson, M. D., Yevtushenko, D. P., & Lu, Z.-X. (2023). Oxidation and thermal degradation of oil during frying: A review of natural antioxidant use. *Food Reviews International*, *39*(7), 4665–4696.

Ganesan, K., & Xu, B. (2020). Deep frying cooking oils promote the high risk of metastases in the breast-A critical review. *Food and Chemical Toxicology*, *144*, 111648.

Ghaffar, N., & Perveen, A. (2025). Solvent polarity effects on extraction yield, phenolic content, and antioxidant properties of Malvaceae family seeds: A comparative study. *New Zealand Journal of Botany*, *63*(4), 627–637.

Gulcin, İ., & Alwasel, S. H. (2023). DPPH radical scavenging assay. *Processes*, *11*(8), 2248.

Guo, Q., Gao, S., Sun, Y., Gao, Y., Wang, X., & Zhang, Z. (2016). Antioxidant efficacy of rosemary ethanol extract in palm oil during frying and accelerated storage. *Industrial Crops and Products*, *94*, 82–88.

Hagos, M., Chandravanshi, B. S., Redi-Abshiro, M., & Yaya, E. E. (2023). Determination of total phenolic, total flavonoid, ascorbic acid contents and antioxidant activity of pumpkin flesh, peel and seeds. *Bulletin of the Chemical Society of Ethiopia*, *37*(5).

Hussain, S. Z., Naseer, B., Qadri, T., Fatima, T., & Bhat, T. A. (2021). Anola (Emblica officinalis): Morphology, taxonomy, composition and health benefits. In *Fruits grown in highland regions of the himalayas: Nutritional and health benefits* (pp. 193–206). Springer.

Jaiboonma, A., Janvikul, W., & Poeaim, S. (2018). *The bioactivities of seed coat and embryo extracts from Indian gooseberry (Phyllanthus emblica).*

Johnson, J., Mani, J., Ashwath, N., & Naiker, M. (2020). Potential for Fourier transform infrared (FTIR) spectroscopy toward predicting antioxidant and phenolic contents in powdered plant matrices. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, *233*, 118228.

Kamalesh, R., Saravanan, A., Yaashikaa, P., & Vijayasri, K. (2025). Innovative approaches to harnessing natural pigments from food waste and by-products for eco-friendly food coloring. *Food Chemistry*, *463*, 141519.

Kaur, M., Sharma, A., Bhardwaj, P., Kaur, H., & Uppal, S. K. (2021). Evaluation of physicochemical properties, nutraceuticals composition, antioxidant, antibacterial and antifungal potential of waste amla seed coat (Phyllanthus emblica, variety Neelam).

Journal of Food Measurement and Characterization, *15*(2), 1201–1212.

Kedir, W. M., Geletu, A. K., Weldegirum, G. S., & Sima, M. F. (2023). Antioxidant activity of selected plants extract for palm oil stability via accelerated and deep frying study. *Heliyon*, *9*(7).

Li, P., Yang, X., Lee, W. J., Huang, F., Wang, Y., & Li, Y. (2021). Comparison between synthetic and rosemary-based antioxidants for the deep frying of French fries in refined soybean oils evaluated by chemical and non-destructive rapid methods. *Food Chemistry*, *335*, 127638.

Lohvina, H., Sándor, M., & Wink, M. (2021). Effect of ethanol solvents on total phenolic content and antioxidant properties of seed extracts of fenugreek (Trigonella foenum-graecum L.) varieties and determination of phenolic composition by HPLC-ESI-MS. *Diversity*, *14*(1), 7.

Metzner Ungureanu, C.-R., Poiana, M.-A., Cocan, I., Lupitu, A. I., Alexa, E., & Moigradean, D. (2020). Strategies to improve the thermo-oxidative stability of sunflower oil by exploiting the antioxidant potential of blueberries processing byproducts. *Molecules*, *25*(23), 5688.

Nadheesha, M., Bamunuarachchi, A., Edirisinghe, E., & Weerasinghe, W. (2011). Studies on antioxidant activity of Indian gooseberry fruit and seed. *Journal of Science of the University of Kelaniya*, *3*.

Namjoo, M., Moradi, M., Niakousari, M., & Karparvarfard, S. H. (2023). Ultrasound-assisted air drying of cumin seeds: Modeling and optimization by response surface method. *Heat and Mass Transfer*, *59*(6), 1073–1091.

Poltanov, E. A., Shikov, A. N., Dorman, H. D., Pozharitskaya, O. N., Makarov, V. G., Tikhonov, V. P., & Hiltunen, R. (2009). Chemical and antioxidant evaluation of Indian gooseberry (Emblica officinalis Gaertn., syn. Phyllanthus emblica L.) supplements. *Phytotherapy Research: An International Journal Devoted to Pharmacological and Toxicological Evaluation of Natural Product Derivatives*, *23*(9), 1309–1315.

Prananda, A. T., Dalimunthe, A., Harahap, U., Simanjuntak, Y., Peronika, E., Karosekali, N. E., Hasibuan, P. A. Z., Syahputra, R. A., Situmorang, P. C., & Nurkolis, F. (2023). Phyllanthus emblica: A comprehensive review of its phytochemical composition and pharmacological properties. *Frontiers in Pharmacology*, *14*, 1288618.

Qi, D., Li, S., & Zhang, Q. (2022). *Effect of ethanol extract of pomegranate peels on the oxidative stability of frying oil and acrylamide content during deep frying of French fries.*

Saeed, A., Shabbir, A., & Khan, A. (2024). Stabilization of sunflower oil by using potato peel extract as a natural antioxidant. *Biomass Conversion and Biorefinery*, *14*(4), 5275–5284.

Saeed, M. K., Zahra, N., Shahadat, N., Shahzadi, K., Abdi, S. H. I., & Syed, Q. (2022). Extraction of poppy seed (Papaver somniferum L.) oil and its antioxidant activity by DPPH assay. *Lahore Garrison University Journal of Life Sciences*, *6*(2), 95–106.

Say, M., Kong, S., Nat, Y., Tan, C., & Tan, R. (2024). *A study on the physicochemical characteristics of popular cooking oils in Cambodia*. *1297*(1), 012002.

Shahidi, F., & Zhong, Y. (2015). Measurement of antioxidant activity. *Journal of Functional Foods*, *18*, 757–781.

Shaikh, J. R., & Patil, M. (2020). Qualitative tests for preliminary phytochemical screening: An overview. *International Journal of Chemical Studies*, *8*(2), 603–608.

Sivakumar, K., & Nallakurumban, B. (2020). Studies on bioactive components retention in sugar based amla products. *INTERNATIONAL JOURNAL*, *11*(2), 39–45.

Suresh, K., Kumaraswamy, M., Sundaravadanam, H., Kadirvel, V., Thirumavalavan, V., & Ganesan, N. D. (2025). Engineering Perspectives on Drying Technologies of Medicinal Plants: A review

on kinetic modelling and bioactive Compounds retention. *Applied Science and Engineering Progress*. https://doi.org/10.14416/j.asep.2025.10.003

Talreja, S., Kumari, S., Srivastava, P., & Pandey, S. (2021). A complete pharmacognostic review on amla. *World. J. Pharm. Pharm. Sci*, *8*, 622–637.

Ujong, A., Emelike, N., Owuno, F., & Okiyi, P. (2023). Effect of frying cycles on the physical, chemical and antioxidant properties of selected plant oils during deep-fat frying of potato chips. *Food Chemistry Advances*, *3*, 100338.

Vats, S., & Gupta, T. (2017). Evaluation of bioactive compounds and antioxidant potential of hydroethanolic extract of Moringa oleifera Lam. From Rajasthan, India. *Physiology and Molecular Biology of Plants*, *23*(1), 239–248.

Wang, P., Wei, J., Hua, X., Dong, G., Dziedzic, K., Wahab, A., Efferth, T., Sun, W., & Ma, P. (2024). Plant anthraquinones: Classification, distribution, biosynthesis, and regulation. *Journal of Cellular Physiology*, *239*(10), e31063.

Xu, X., Liu, A., Hu, S., Ares, I., Martínez-Larrañaga, M.-R., Wang, X., Martínez, M., Anadón, A., & Martínez, M.-A. (2021). Synthetic phenolic antioxidants: Metabolism, hazards and mechanism of action. *Food Chemistry*, *353*, 129488.

Declaration

The authors have no conflicts of interest to declare. All co-authors have seen and agreed with the contents of the manuscript and there is no financial interest to report. The submission is original work and is not under review at any other publication. Upon request, relevant documentation or data will be sent in order to verify the validity of the results presented in the form of raw data, samples and records.