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Proximate analysis, phytochemical profiling and GC–MS characterization of bioactive compounds of ethanolic extract and oil of *Arachis hypogaea*

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Abstract

Arachis hypogaea, commonly known as groundnut or peanut, is a legume cultivated for its food, nutritional and health benefits. The study aims to characterise in detail, the polar and non-polar components of *Arachis hypogaea*. The study was carried out by proximate analysis of the whole groundnut seed, followed by isolation of its polar and non-polar compositions by successive extraction, then phytochemical analysis and gas chromatography-mass spectrometry (GC–MS) analysis of the extracts were carried out following standard experimental protocols. The proximate analysis revealed the residual moisture to be 6.18%; protein 23.84%, fat 36.10%, carbohydrates 27.82%, fibre 3.63%, and ash 2.43%. Phytochemical analysis shows that the non-polar oil of *Arachis hypogaea* contains sterols and terpenoids, while the polar ethanolic extract contains phenolics, flavonoids, tannins, saponins, sterols, and terpenoids. The GC–MS analysis revealed the presence of twenty (20) bioactive compounds in the non-polar oil, with the most abundant being oleic acid, while the polar ethanolic extract contained thirty-four (34) bioactive compounds, with the most abundant being linoelaidic acid. The present study shows that *Arachis hypogaea* contains a rich profile of nutrients including sterols, flavonoid, tannins, sterols and phenolic; and bioactive compounds (oleic acid and linoelaidic acid), with high content of unsaturated fats, proteins, and carbohydrates, coupled with the presence of antioxidants. These bioactive components contribute to its value not only as a nutritional supplement but also as a potential therapeutic agent.

Keywords *Arachis hypogaea*, Phytochemical, Bioactive compounds, Gas chromatography-mass spectrometry, Nutritional properties

1 Introduction

Arachis hypogaea, commonly known as groundnut or peanut, is a legume predominantly cultivated in tropical and subtropical regions. It is believed to originate from South and Central America but is now widely grown across the globe for its nutritional and economic significance [1, 2]. It is cultivated as a significant agricultural crop across



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diverse agroecological zones worldwide, including India, China, Japan, the United States of America, and West Africa; with more than 300 distinct varieties reported globally [1, 3, 4].

Arachis hypogaea is cultivated in various conditions worldwide for its food, nutritional, and health benefits [5, 6]. It is served universally as a snack or dessert or as a major ingredient in several food products like soups, peanut butter and groundnut oil [7–9]. It can be consumed either boiled, roasted or raw [2]. Noteworthy, over 60% of global groundnut produced is crushed and extracted for its oils: while 40% is consumed as food and for other uses [6, 10]. The seeds are approximately 22–30% crude protein and are a great source of protein and healthy fats [11, 12]. *Arachis hypogaea* contain about 50% monounsaturated fatty acids (MUFAs), 33% Polyunsaturated Fatty Acids (PUFAs) and 14% saturated fatty [13, 14], and contain all 20 amino acids in several proportions, as well as its abundance of essential minerals such as copper, manganese, iron, phosphorus, and magnesium; and bioactive antioxidant compounds including phenolic acids, resveratrol, *p*-coumaric acid, tocopherols, and vitamins A, C, and E [6, 13, 15]. *Arachis hypogaea* is also a rich dietary source of biologically active compounds such as flavonoids, arginine which function to regulate hormone production, phytosterols that helps with absorption of cholesterol; polyphenols like resveratrol an antioxidant, and isoflavones [13, 16].

Until the emergence of modern medicine, traditional medicine originating from natural environmental resources was the primary system for healthcare [17, 18]. With the contemporary need for more natural remedies, humanity is now reverting to more natural remedies originating from crops and herbs that possess phytochemicals that are effective in combating various disease conditions [17–19]. The interest in investigating the phytochemical composition of plants, focusing on the isolation, identification and characterization of bioactive components from these plants is growing in the scientific community [20]. Groundnut exhibits significant pharmacological potential due to its rich composition of bioactive compounds, including isoflavonoids, minerals, phytosterols, phenolic acids, proteins, stilbenes and essential fatty acids [15]. These constituents contribute to observed therapeutic effects, with both in vitro and in vivo studies describing anticancer, anti-inflammatory, and sedative or hypnotic properties. Although the chemical and bioactive composition of *Arachis hypogaea* has been investigated [3, 6, 21], comprehensive data on the chemical composition of the polar and non-polar components of the groundnut are not readily available.

This present study is a detailed characterization of the polar (ethanolic extract) and non-polar (oil) components of *Arachis hypogaea*, through proximate analysis of whole groundnut seed, phytochemical and GC–MS analysis of both oil and ethanolic extracts. This is to provide a further assessment of the macronutrient compositions, identify key phytochemicals and bioactive compounds and other metabolites present in the polar and non-polar compositions of *Arachis hypogaea* species present in our environment, to identify its nutritional properties and further expand its potential medicinal applications.

2 Materials and methods

2.1 Collection, identification, and preparation of *Arachis hypogaea*

Fresh groundnuts (Samnut series) harvested in the dry season, were purchased from a crop produce market in Rumuokoro, Obio Akpor local government area, Rivers state, Nigeria. The groundnuts were identified and authenticated at the Department of Plant Science and Biotechnology, University of Port Harcourt, and assigned the voucher number UPH/P/447. Groundnuts seeds were air dried for 2wks and pulverized into powder for maceration process. A measured sample (1000 g) of the pulverized groundnut was dissolved in 2000 ml of N-Hexane in a glass jar for 72 h. The mixture was then filtered with the aid of filter paper, while the filtrate was concentrated using a rotary evaporator at 50 °C to yield an oil extract (non-polar fraction). The remaining shafts were further air-dried for 24 h before dissolving 750 g in 1500 ml of ethanol in a glass jar for 48 h. The filtrate was concentrated in a rotary evaporator at 45 °C to further yield an ethanolic extract (polar fraction). Samples were collected in glass jars and stored in refrigerator at 3 °C until required for various analysis.

2.2 Proximate analysis of *Arachis hypogaea*

Air-dried groundnut seeds were analyzed for proximate composition, including moisture, fat, protein, ash, and total carbohydrate content using standard AOAC methods [22].

Protein determination: The Kjeldahl method estimates crude protein content by measuring total nitrogen was used for protein determination. The sample is digested with sulfuric acid and a catalyst, converting all nitrogen into ammonium sulfate. This is then neutralized with sodium hydroxide, releasing ammonia gas. The ammonia is captured in boric acid and titrated with hydrochloric acid to determine the nitrogen content. Because proteins contain approximately 16% nitrogen, the nitrogen value is multiplied by 6.25 to calculate crude protein. This method accounts for all nitrogen, including non-protein nitrogen, and may overestimate true protein content in species with high levels of non-protein nitrogen compounds like urea.

Formula:

$$\begin{aligned} \% \text{Nitrogen content} \\ = \frac{(\text{ml of standard acid} - \text{ml of blank}) \times N \text{ of Acid} \times 1.4007}{\text{weight of sample in grams}} \end{aligned}$$

2.3 Moisture content determination

The moisture content was measured by first weighing the sample in a porcelain crucible. The crucible containing the sample was then heated in an electric oven at 105 °C for approximately 6 h. After heating, it was allowed to cool in a desiccator before being reweighed.

Formula:

$$\% \text{moisture content} = \frac{\text{weight of moisture obtained (g)}}{\text{weight of sample (g)}} \times 100$$

Ash content determination: The ash content was determined by combusting 2 g of the sample in a muffle furnace at 550 °C for 45 min, following the AOAC method. The

remaining inorganic residue (ash) was then weighed after cooling in a desiccator, providing a measure of the total mineral content.

Formula:

$$\% \text{ Ash} = \frac{\text{weight of Ash (g)}}{\text{Initial weight of sample (g)}} \times 100$$

Crude lipid determination: was determined using Soxhlet extraction. 3 g of sample is placed in a thimble and extracted with ethyl ester. The solvent is evaporated, and the remaining lipid residue is dried in an oven at 100 °C for 30 min to remove residual solvent if any. It is then cooled in a desiccator, and then weighed to determine the total fat content.

Formula:

$$\% \text{ Fat} = \frac{\text{weight of fat/lipid obtained (g)}}{\text{weight of sample (g)}} \times 100$$

Carbohydrate (nitrogen-free extract) determination: the carbohydrate content, also known as the Nitrogen-Free Extract (NFE), was calculated by adding the values of other analysed nutrients and subtracting the total from 100.

2.4 Phytochemical screening

Alkaloids [23]: The samples were first dissolved individually in dilute hydrochloric acid and filtered. Mayer's Test: Filtrates were treated with Mayer's reagent (potassium mercuric iodide). Formation of a yellow-coloured precipitate indicates the presence of alkaloids.

Saponins [24]: The samples were diluted in 20 ml of water and shaken in a cylinder for 15 min. A formation of 1 cm of foam indicates presence of saponins.

Terpenoids [25]: The samples were treated with chloroform and filtered through filter paper, the filtrate was treated with a few drops of concentrated Sulphuric acid, shaken and allowed to stand. Golden yellow colouration appearance indicates presence of triterpenes.

Sterols [24]: The samples were treated with chloroform and filtered through filter paper, the filtrate was treated with few drops of acetic anhydride, boiled and cooled, concentrated sulphuric acid was then added. Brown ring formation at the junction indicates the presence of phytosterols.

Phenols [23]: The extracts were treated with 3–4 drops of ferric chloride solution. The formation of blue-black colour indicated the presence of phenols.

Tannins [23]: A 1% gelatin solution containing sodium chloride was added to the oil and extract. The formation of white precipitate indicates the presence of tannins.

Flavonoids [26]: The samples were treated with few drops of sodium hydroxide solution. The formation of a deep yellow colour that turns colourless when dilute acid is added, indicates the presence of flavonoids.

Phlobatannins [24]: 1% aqueous hydrochloric acid was added to samples and boiled; the deposition of a red precipitate, indicates the presence of phlobatannins.

Cardiac glycosides [25]: 5 ml of each sample was treated with 2 ml of glacial acetic acid with 2 drops of ferric chloride added, carefully underlayered with 1 ml of concentrated

sulphuric acid. A brown ring indicates the presence of deoxysugar that characterizes cardenolides.

2.5 Determination of LD_{50}

Acute toxicity test of *Arachis Hypogaea* was done using the Lorke's method [27, 28]. The study was done in two phases, six (6) male mice, divided into three (3) groups of two (2) animals each was given oil of *Arachis hypogaea* at dosage of 1000 mg/kg, 2000 mg/kg and 4000 mg/kg, and 1000 mg/kg, 2000 mg/kg and 4000 mg/kg of ethanolic extract respectively in phase one. The second phase comprised of six (6) male mice divided into groups of two (2) animals each, given 4000 mg/kg, 8000 mg/kg and 16,000 mg/kg oil of *Arachis hypogaea* and 1000 mg/kg, 3000 mg/kg and 6000 mg/kg of ethanolic extract of *Arachis hypogaea*. Animals were closely monitored for signs of toxicity and mortality.

The LD_{50} was calculated as follows:

$$LD_{50} = \sqrt{D0 \times D100}$$

where D0 = Highest dose that gave no mortality.

D100 = Lowest dose that produced mortality.

2.6 Gas chromatography and mass spectrometry (GC–MS) analysis

The oil and ethanolic extracts of *Arachis hypogaea* were analyzed using a Shimadzu GC–MS QP2010 Plus system (GC7990A/MC-5975C, Santa Clara, USA) equipped with a Thermal Desorption System (TD 20) and a Restek XTI-5 column. The prepared samples were filtered through a 0.22 µm filter to remove particulate matter. The GC–MS instrument was set up with a Restek XTI-5 column, using helium as the carrier gas at a flow rate of 1.2 mL/min. The TD 20 parameters were optimized to ensure complete analyte transfer. The GC oven temperature program began at 50 °C for 1 min, followed by a linear increase of 10 °C/min to 220 °C, held for 3 min, and then a further linear increase of 10 °C/min to 290 °C, held for 10 min. The mass spectrometer operated in electron ionization (EI) mode at 70 eV, and the mass range was optimized for the target analytes. Prepared samples were injected into the GC–MS system via thermal desorption, and total ion chromatograms (TICs) and mass spectra were acquired for each eluting compound. Chromatograms were processed using Shimadzu GC–MS solution software. Compounds were identified by comparing their retention times and fragmentation patterns with the mass spectra obtained from the GC–MS. The identities of active components was verified by comparing their retention indices, peak area percentages, and mass spectral fragmentation patterns against the NIST library. The identified compounds and their concentrations were reported. Method validation was performed to ensure the result accuracy, precision, and reliability, including determination of linearity, accuracy, precision, limit of detection (LOD), and limit of quantification (LOQ). Proper sample preparation, including optimization of thermal desorption parameters if applicable, was crucial for accurate results, and quality control samples were used throughout the analysis.

Table 1 Proximate analysis of *Arachis hypogaea* seed

Phytochemical	Ethanol extract	Oil
Phenolics	+ + ve	– ve
Flavonoids	+ + ve	– ve
Tannins	+ ve	– ve
Saponins	+ ve	– ve
Sterols	+ ve	+ + ve
Terpenoids	+ ve	+ ve
Alkaloids	– ve	– ve
Cardiac Glycosides	– ve	– ve
Phlobatanins	– ve	– ve

–, No precipitation; +, Slight precipitation; + +, Medium precipitation

Table 2 Phytochemistry of polar ethanolic extract and non-polar oil of *Arachis hypogaea*

S/N	Component	Composition (%)
1	Moisture	6.18 ± 0.01
2	Protein	23.84 ± 0.01
3	Fat	36.10 ± 0.01
4	Carbohydrates	27.82 ± 0.01
5	Fibre	3.63 ± 0.01
6	Ash	2.43 ± 0.01

3 Results

3.1 Proximate analysis

Table 1. shows the proximate analysis of whole *Arachis hypogaea*. Highlighting the residual moisture, protein, fat, carbohydrates, fibre, and ash content of the whole seed of *Arachis hypogaea*.

3.2 Phytochemical analysis

Table 2. presents the qualitative analysis of the phytoconstituents present in the polar ethanolic extract and the non-polar oil of *Arachis hypogaea*. The non-polar oil of *Arachis hypogaea* contain sterols, and terpenoids, while the polar ethanolic extract contain phenolics, flavonoids, tannins, saponins, sterols, and terpenoids. This phytochemical profiling of both the polar and non-polar fractions of *Arachis hypogaea* did not show the presence of alkaloids, cardaic glycosides and phlobatanins.

3.3 Acute toxicity study

Table 3 shows the lethal doses *Arachis hypogaea* extracts. The LD₅₀ of the non-polar oil in this study was determined to be 5656.85 mg/kg, where administration of 4000 mg/kg of the oil extract did not lead to any mortality in test group while administration of 8000 mg/kg of oil extract lead to partial mortality in the test group. The table also show the lethal dose of the polar ethanolic *Arachis hypogaea* determined to be 1732.05 mg/kg, where adminstration of 1000 mg/kg of ethanolic extract did not cause any mortality in test group while adminsitartion of 3000 mg/kg of ethanolic extract lead to partial mortality in test group.

3.4 Gas chromatography and mass spectrometry (GC–MS) analysis

Table 4 shows a listing of bioactive compounds identified in the non-polar oil of *Arachis hypogaea*; a total of twenty (20) compounds were detected. The most abundant being

Table 3 The lethal dose (LD₅₀) of polar ethanolic extract and non-polar oil of *Arachis hypogaea*

Phase	Polar ethanolic extract			Non-polar oil		
	Dose (mg/kg)	No of animals	No of deaths	Dose (mg/kg)	No of animals	No of deaths
1	1000	3	0	100	3	0
1	2000	3	1	2000	3	0
1	4000	3	3	4000	3	0
2	1000	3	0	4000	3	0
2	3000	3	1	8000	3	1
2	6000	3	3	16,000	3	3

$$LD_{50} = \sqrt{D0 \times D100}$$

Where D0=Highest dose that gave no mortality

D100=Lowest dose that produced mortality

Using the above formula, LD₅₀ for ethanolic extract was determined to be 1732.05 mg/kg, while LD₅₀ for the oil was determined to be 5056.85 mg/kg

Table 4 The gas chromatography-mass separation (GC–MS) of non-polar oil of *Arachis hypogaea*

S/N	Retention time (minutes)	Name of compound	Chemical formula	Molecular weight (g/mol)	Area (%)
1	13.564	Hexadecanoic acid, methyl ester	C ₁₇ H ₃₄ O ₂	270.4507	4.10
2	13.839	Dibutyl phthalate	C ₁₆ H ₂₂ O ₄	278.34	4.57
3	13.839	1,2-Benzenedicarboxylic acid, bis(1-methylethyl) ester	C ₁₄ H ₁₈ O ₄	250.2903	4.57
4	13.971	n-Hexadecanoic acid	C ₁₆ H ₃₂ O ₂	256.4241	16.87
5	13.971	Tridecanoic acid	C ₁₃ H ₂₆ O ₂	214.34	16.87
6	14.932	11,14-Octadecadienoic acid, methyl ester	C ₁₉ H ₃₄ O ₂	294.5	6.04
7	14.932	9,12-Octadecadienoic acid (Z,Z)-, methyl ester	C ₁₉ H ₃₄ O ₂	294.4721	6.04
8	15.184	Methyl stearate	C ₁₉ H ₃₈ O ₂	298.5	1.12
9	15.407	Oleic Acid	C ₁₈ H ₃₄ O ₂	282.5	48.73
10	15.538	Decanoic acid, silver(1 +) salt	C ₁₀ H ₂₀ AgO ₂	280.13	3.34
11	15.687	9,12-Octadecadienoic acid (Z,Z)-	C ₁₈ H ₃₂ O ₂	280.4455	1.58
12	15.687	Linoelaidic acid	C ₁₈ H ₃₂ O ₂	280.4	1.58
13	17.638	Decanoic acid, 2-hydroxy-3-[(1-oxooctyl)oxy]propyl ester	C ₂₁ H ₄₀ O ₅	372.5393	1.01
14	17.638	3-(Octanoyloxy)propane-1,2-diyl bis(decanoate)	C ₃₁ H ₅₈ O ₆	526.7886	1.01
15	19.195	Lauric anhydride	C ₂₄ H ₄₆ O ₃	382.6	2.97
16	19.195	4-Nitrophenyl laurate	C ₁₈ H ₂₇ NO ₄	321.4	2.97
17	19.195	3-(Octanoyloxy)propane-1,2-diyl bis(decanoate)	C ₃₁ H ₅₈ O ₆	526.7886	2.97
18	20.356	4-Dibenzofuranamine	C ₁₂ H ₉ NO	183.21	1.04
19	20.356	Fumaric acid, 2-methylpentyl 2-chloro-6-fluorophenyl ester	C ₁₆ H ₁₈ ClFO ₄	328.763	1.04
20	20.356	1,3-butanedione, 1-[4-(2-hydroxyethyl)-1-piperazinyl]-	C ₁₃ H ₁₂ N ₄ O ₃	272.26	1.04

oleic acid (48.73%); n-Hexadecanoic acid; tridecanoic acid; and 11,14-Octadecadienoic acid methyl ester.

Figure 1 shows the total ion chromatogram analysis of the non-polar oil of *Arachis hypogaea*. The figures show several dominant peaks between retention time 13.0 and 16.0, with the most intense peak at RT 15.407 min, indicating the presence of a major fatty acid—oleic acid.

Table 5 shows a listing of bioactive compounds identified in the polar ethanolic extract of *Arachis hypogaea*; with a total of thirty-four (34) compounds detected. The most abundant being linoelaidic Acid (30.45%); n-Hexadecanoic acid; oleic acid; and 5-Hydroxymethylfurfural.

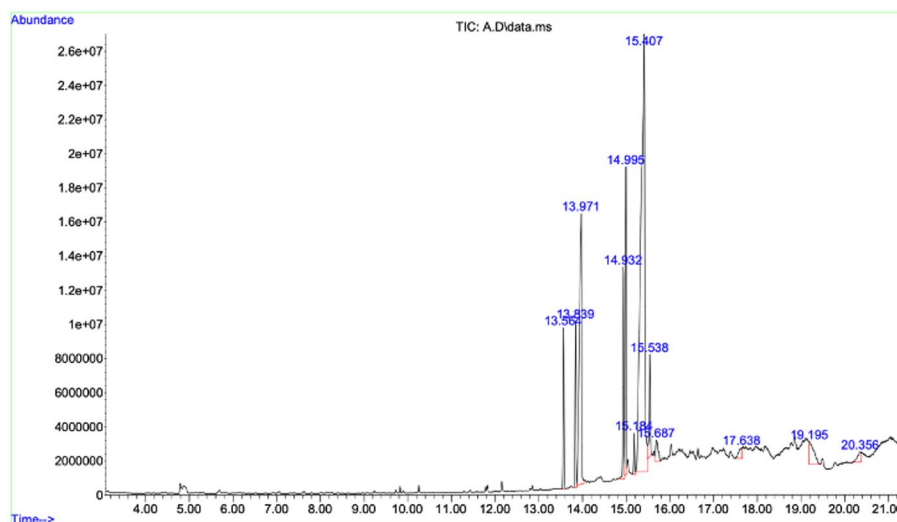


Fig. 1 Total ion chromatogram (TIC) analysis of non-polar oil *Arachis hypogaea*

Figure 2 shows the total ion chromatogram analysis of the polar ethanolic extract of *Arachis hypogaea*. The figure shows a number of peaks with small to medium intensities between 2 and 10 min, indicating the presence of low molecular weight compounds. A prominent sharp peak was observed at RT 15.458 min indicating the presence of a predominant bioactive compound—linoleic acid.

4 Discussion

There is growing interest in identifying and isolating the diverse phytochemical and bioactive compounds present in plant-based remedies, driven by the increasing demand for natural therapeutic solutions [18]. The present investigation aims to elucidate the chemical profiles of the polar and non-polar fractions of *Arachis hypogaea*. Utilizing proximate analysis, phytochemical screening, and gas chromatography-mass spectrometry (GC-MS), we sought to identify key bioactive compounds within this food crop, known to possess a rich profile of Isoflavonoids, flavonoids, and essential minerals, contributing to its recognized medicinal and nutritional benefits.

4.1 Proximate analysis

The proximate analysis of whole *Arachis hypogaea* revealed a nutritional profile rich in macronutrients. The low moisture content (6.18%) (Table 1) shows that the sample is less prone to spoilage and good for storage. The high fat content (36.10%) (Table 1) shows that *Arachis hypogaea* as a source of energy as the primary fatty acids are essential for cell membrane structure, hormone production, and absorption of the fat-soluble vitamins [29, 30]. They also provide essential fatty acids such as linoleic and alpha-linolenic acids, that the human body cannot synthesize [31, 32]. Unlike simple sugars, the complex carbohydrates content present in *Arachis hypogaea* (27.82%) (Table 1) provides sustained energy release, further contributing to dietary fibre required for digestion and blood sugar [33]. The protein content (23.84%) is essential for enzyme production, immune function, and tissue repairs [29]. The fibre content (3.63%) (Table 1) is crucial for bowel movement and functioning to help lower cholesterol levels [34, 35]. Ash content (2.34%) (Table 1) representing the presence of essential minerals like calcium, iron,

Table 5 The gas chromatography-mass separation (GC–MS) of polar ethanolic extract of *Arachis hypogaea*

S/N	Retention time (minutes)	Name of compound	Chemical formula	Molecular weight (g/mol)	Area (%)
1	3.207	2-Furancarboxaldehyde, 5-methyl-	C ₆ H ₆ O ₂	110.1106	0.96
2	3.740	2-Hexanone, 4-methyl-	C ₇ H ₁₄ O	114.19	1.77
3	3.740	1-Pentene, 2,4,4-trimethyl-	C ₈ H ₁₆	112.21	1.77
4	4.249	Benzeneacetaldehyde	C ₈ H ₈ O	120.1485	1.40
5	4.649	2,5-Furandicarboxaldehyde	C ₆ H ₄ O ₃	124.09	2.54
6	4.649	Orcinol	C ₇ H ₈ O ₂	124.139	2.54
7	4.649	2,4-Diaminophenol	C ₆ H ₈ N ₂ O	124.14	2.54
8	4.730	2,5-Furandicarboxaldehyde	C ₆ H ₄ O ₃	124.09	1.22
9	5.119	1-Isopropyl-2,2-dimethylpropylideneamine	C ₁₅ H ₃₃ N	227.43	1.78
10	5.119	Pyrrolidine, 2-(hydroxymethyl)-	C ₅ H ₁₁ NO ₃	133.15	1.78
11	5.119	Cyclohexanol, 2-amino-1-methyl-4- 1-methylethyl)-	C ₁₀ H ₂₀ O	156.2652	1.78
12	6.738	5-Hydroxymethylfurfural	C ₆ H ₆ O ₃	126.11	7.23
13	12.346	N-Serylserine	C ₆ H ₁₂ N ₂ O ₅	192.17	2.88
14	12.346	Silane, ethyl trimethyl-	C ₅ H ₁₄ Si	102.25	2.88
15	12.346	alpha.-Methyl mannofuranoside	C ₇ H ₁₄ O ₆	194.18	2.88
16	13.845	1,2-Benzenedicarboxylic acid, butyl 2-ethylhexyl ester	C ₂₀ H ₃₀ O ₄	334.4498	1.99
17	13.845	Dibutyl phthalate	C ₁₆ H ₂₂ O ₄	278.34	1.99
18	14.045	n-Hexadecanoic acid	C ₁₆ H ₃₂ O ₂	256.42	15.11
19	14.932	9,12-Octadecadienoic acid, methylester, (E,E)-	C ₁₉ H ₃₄ O ₂	294.4721	1.18
20	15.458	Linoelaidic acid	C ₁₈ H ₃₂ O ₂	280.45	30.45
21	15.487	Oleic Acid	C ₁₈ H ₃₄ O ₂	282.5	5.28
22	15.630	Octadecanoic acid	C ₁₈ H ₃₆ O ₂	284.4772	2.77
23	15.630	Tetradecanoic acid	C ₁₄ H ₂₈ O ₂	228.3709	2.77
24	16.557	Fumaric acid, 2-dimethylaminoethyl tetradecyl ester	C ₁₇ H ₃₁ NO ₄	313.4	0.99
25	16.557	Fumaric acid, 2-dimethylaminoethyl octadecyl ester	C ₂₆ H ₄₉ NO ₄	439.7	0.99
26	16.557	2-Dodecanone	C ₁₂ H ₂₄ O	184.32	0.99
27	18.571	Diltiazem	C ₂₂ H ₂₆ N ₂ O ₄ S	414.52	1.20
28	18.571	Pargeverine	C ₂₁ H ₂₃ NO ₃	337.4	1.20
29	18.571	2-Propenoic acid, 2-(dimethylamino) ethyl ester	C ₇ H ₁₃ NO ₂	143.1836	1.20
30	18.651	Fumaric acid, 2-dimethylaminoethyl heptadecyl ester	C ₂₅ H ₄₇ NO ₄	425.654	1.28
31	18.651	Carbonic acid, butyl 2-dimethylaminoethyl ester	C ₇ H ₁₅ NO ₃	161.20	1.28
32	18.651	Bis(2-(Dimethylamino)ethyl) ether	C ₈ H ₂₀ N ₂ O	160.26	1.28
33	19.601	Hexadecanoic acid, 2-hydroxy-1-(hydroxymethyl)ethyl ester	C ₁₉ H ₃₈ O ₄	330.5026	6.36
34	19.601	15-Hydroxypentadecanoic acid	C ₁₅ H ₃₀ O ₃	258.3969	6.36

magnesium and potassium, vital for physiological processes including nerve function, electrolyte homeostasis, and bone formation and maintenance [36]. These findings are in line with deductions from other studies by Sanni et al. and Atasie et al. where the average moisture, protein, fat, fibre, carbohydrate and ash composition are 5.80%, 38.61%, 47.00%, 3.70%, 1.81%, and 3.08% respectively [37, 38].

4.2 Phytochemical analysis

The phytochemical screening revealed a distinct variation in the distribution of bioactive compounds between the polar and non-polar fractions of *Arachis hypogaea*. The presence of sterols and terpenoids in the both fractions, suggest cardioprotective and anti-inflammatory potential of the extracts. The sterols indicates its' cholesterol-lowering activity, as the predominant sterols such as β -sitosterol, campesterol and stigmasterol

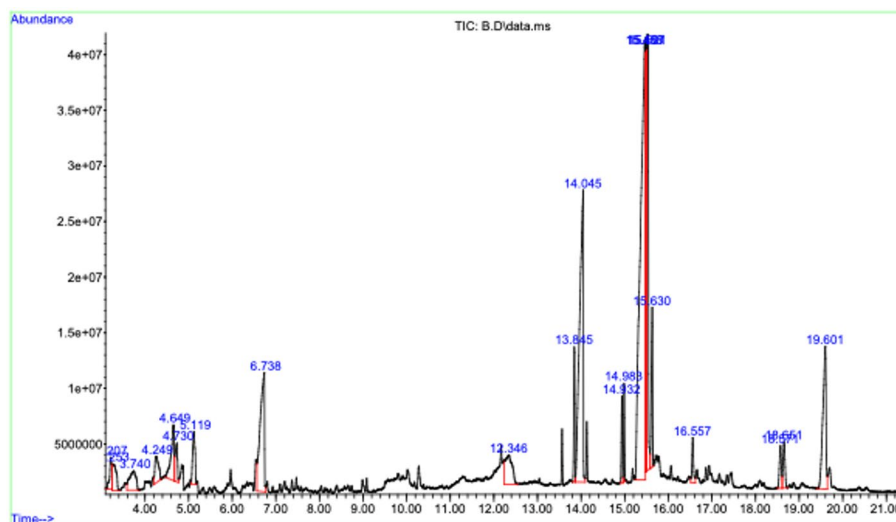


Fig. 2 Total ion chromatogram (TIC) analysis of polar ethanolic extract of *Arachis hypogaea*

are well recognized in their action of cholesterol lowering [39, 40]. Sterols also have anti-inflammatory activity, antioxidant and immunomodulatory effects, indicating the possible relevance of the extract in managing metabolic and inflammatory disorders [41, 42]. The terpenoid constituents further enhances its' medicinal profile as various sesquiterpenes and triterpenes possess antioxidant, anti-inflammatory, antibacterial, and cytoprotective properties [43, 44].

The polar ethanolic extract however demonstrated the presence of a broader phytochemical profile, including phenolics, flavonoids, tannins, and saponins, elucidating its potency as an antioxidant and anti-inflammatory agent [18, 19, 45]. Phenolics, characterized by aromatic rings and hydroxyl groups, have been shown both in vitro and in vivo studies to scavenge free radicals, modulate inflammatory pathways, and exhibit antimicrobial activity [46, 47]. Flavonoids, a subgroup of phenolics, share similar antioxidant and anti-inflammatory properties and have demonstrated neuroprotective effects [18]. Tannins, complex polyphenols, possess astringent properties, and contributing to antimicrobial activity [48, 49].

Studies show that other parts of the plant show similar phytochemical profile; where extracts from the seeds, skin and root of *Arachis hypogaea* showed a rich phytochemical profile including phenolic acids, flavonoids, stilbenes, phytosterol, essential amino acids and other micro nutrients [50–54].

4.3 Acute toxicity study

The non-polar oil exhibits very low acute toxicity with no mortality or adverse behavioral or physiological effects observed at high doses less than 8000 mg/kg (Table 3). According to the OECD toxicity classification, the non-polar oil is non-toxic when administered orally to rat models. The polar ethanolic extract showed partial mortality at high dose of 3000 mg/kg (Table 3), categorizing it as having low acute toxicity. This finding indicates a wide safety margin relative to the typical therapeutic doses.

Nagendra et al. in their study of the immunomodulatory activity of aqueous extract of *Arachis hypogaea* seeds, as well as Gul et al., noted the low toxicity of extracts of *Arachis hypogaea* in determination of doses for administration in their rat models [55, 56].

4.4 Gas chromatography and mass spectrometry (GC–MS) analysis

The GC–MS profile of the non-polar oil of *Arachis hypogaea* was dominated by long-chain fatty acids and related lipophilic constituents, with oleic acid, n-Hexadecanoic (palmitic) acid, tridecanoic acid, 11, 14-Octadecadienoic acid, and 9,12-Octadecadienoic; as the five (5) most abundant (with area concentration > 5%). This composition is consistent with reports of the chemistry of groundnut oil, elucidating its physiochemical components seen in the present study and further linking it to cardioprotective and anti-inflammatory effects. Oleic acid which is most occurring in the non-polar fraction has numerous health benefits, including cardiovascular benefits like reduction in LDL cholesterol, and the ability to lower blood pressure [57]. It also has anti-inflammatory effects, modulating inflammatory markers and reducing oxidative stress [58, 59]. Oleic acid has been shown to also positively affect weight management as it promotes fat oxidation and improves insulin sensitivity, thus helping in managing obesity-related diseases and reducing the risk of type 2 diabetes [60]. It has also been implicated in cancer prevention, as new research suggests that it may inhibit the growth of cancer cells [61, 62]. Palmitic acid is involved in lipid metabolism, serving as a precursor for the synthesis of phospholipids and triglycerides. It functions as an antioxidant, protecting from cell damage resulting from reactive oxygen species [18]. Beyond its nutritional role, palmitic acid exhibits antimicrobial and anti-inflammatory properties, implicating it as a valuable pharmaceutical as an anticancer agent [63]. Other reports where both crude and ozonized *Arachis hypogaea* oil were analyzed for their chemical composition, were further used to significantly enhance antimicrobial, antioxidant, anti-inflammatory and anticancer activities [64]. Another study on fatty acids of four different species of *Arachis hypogaea* oil Myanmar, in southeast Asia showed high concentrations of fatty acids including oleic and linoleic acids as observed in our present study [65].

The polar ethanolic extract contained a more chemically diverse array of somewhat volatile and polar active compounds (34) with linoelaidic acid, 5-Hydroxymethylfurfural, hexadecanoic acid, 2-hydroxyl-1-(hydroxymethyl)ethyl ester, and 15-Hydroxypentadecanoic acid; as the five (5) most abundant (with area concentration > 5%). Linoelaidic acid as a trans fatty acid can arise from isomerization, having different metabolic and inflammatory profiles than cis-linoleic acid. While linoleic acid can be seen to have to anti-inflammatory effect with their ability to be metabolized into compounds like gamma-linolenic acid (GLA), which can counteract chronic inflammation and support the immune system [66], the alteration in Linoelaidic acids' chemical structure makes it different from linoleic acid, causing it to increase LDL cholesterol, and decrease HDL cholesterol, thereby contributing to the risk of heart disease, further increasing risk of inflammation, insulin resistance, obesity and other metabolic disorders [67]. 5-HMF is commonly found in heat-processed foods such as honey, coffee, dried fruits, and roasted peanuts [68]. It has notable antioxidant properties, acting as a free radical scavenger and helping to reduce oxidative stress, lowering the risk of diseases and oxidative damage to heart tissues [69], functioning as anti-inflammatory agent, by modulating inflammatory pathways; with studies suggesting that 5-HMF has anticancer potentials, as it may induce apoptosis in cancer cells [69, 70].

Although the ethanolic fraction is rich in oxygenated lipids, the presence of both trans-fatty species and 5-HMF may plausibly explain the observed toxicity at lower doses (Table 3) if present at biologically active concentrations. These observations are

consistent with the observations by Andersen and his colleague in their report on the safety assessment of *Arachis hypogaea* oil and others [71].

5 Conclusion

This comprehensive investigation of *Arachis hypogaea*; encompassing proximate composition, phytochemical screening, and GC–MS characterization of both polar and non-polar extracts, revealed a diverse profile of nutrients and bioactive constituents. The presence of various macro, and bioactive compounds in both extracts underscores the nutritional and therapeutic potential of *Arachis hypogaea*.

Author contribution

AGO and BCC conceptualized the study. AGO conducted the experiments, performed data analysis and interpretation, and drafted the manuscript. BCC and DVD supervised the study, reviewed the protocols, and revised and approved the final version of the manuscript.

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Data availability

All datasets generated and analysed during the current study are used and presented in the manuscript and can be made available from the corresponding author on reasonable request.

Declarations

Ethics approval

The research design and protocol were approved by the University of Port Harcourt ethics committee (UPH/CEREMAD/REC/MM106/004). The plant material (*Arachis hypogaea* L.) used in this study was obtained from cultivated sources and handled in accordance with relevant local and national guidelines for plant research. Animals were handled following ethical standard in animal experimentation. No protected or endangered species were involved in this study, and no specific permits were required for the collection of the plant material.

Consent to participate

Not applicable.

Consent to publish

All authors have read and approved this final manuscript and consent to its publication.

Competing Interest

The authors declare no competing interests.

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References

1. Settaluri VS, Kandala CVK, Puppala N, Sundaram J. Peanuts and their nutritional aspects—a review. *Food Nutr Sci*. 2012. <https://doi.org/10.4236/fns.2012.312215>.
2. Toomer OT. Nutritional chemistry of the peanut (*Arachis hypogaea*). *Crit Rev Food Sci Nutr*. 2018;58:3042–53. <https://doi.org/10.1080/10408398.2017.1339015>.
3. Jain A, Prakash M, Radha C. Extraction and evaluation of functional properties of groundnut protein concentrate. *J Food Sci Technol*. 2015;52:6655–62. <https://doi.org/10.1007/s13197-015-1758-7>.
4. Radhakrishnan T, Rathnakumar AL, Mahatma MK, Chandramohan S, Patel S. Genetic resources of groundnut. In: Priyadarshan PM, Jain SM, editors. *Cash crops genetic diversity erosion conservation utility*. Cham: Springer; 2022. p. 341–406.
5. Improving cultivation of groundnuts. Burleigh Dodds Ser. Agric. Sci. Burleigh Dodds; 2018. Science Publishing, pp 155–180.
6. Ranathunga R, Amarasinghe Y, Gunasekara G. Chemical and physical properties of Sri Lankan medium seeded groundnuts (*Arachis hypogaea* L.) genotypes. *J AgriSearch*. 2017. <https://doi.org/10.21921/jas.v4i1.7420>.
7. Nwokolo E. Peanut (*Arachis hypogaea* L.). In: Nwokolo E, Smartt J, editors. *Food feed legum oilseeds*. Boston: Springer; 1996. p. 49–63.
8. Ory RL, Flick GJ. Peanut and cottonseed proteins for food uses. In: Hudson BJF, editor. *New deviation sources food proteins*. Boston: Springer; 1994. p. 195–240.
9. Vishnu VS. Scope of entrepreneurship developments in groundnut processing. *Entrep Dev Food Process*. 2021.
10. Isanga J, Zhang G-N. Biologically active components and nutraceuticals in peanuts and related products: review. *Food Rev Int*. 2007;23:123–40.
11. Oso AA, Ashafa AO. Nutritional composition of grain and seed proteins. *Grain Seed Proteins Funct*. 2021. <https://doi.org/10.5772/intechopen.97878>.
12. Poutanen KS, Kärilund AO, Gómez-Gallego C, et al. Grains – a major source of sustainable protein for health. *Nutr Rev*. 2022;80:1648–63. <https://doi.org/10.1093/nutrit/nuab084>.

13. Arya SS, Salve AR, Chauhan S. Peanuts as functional food: a review. *J Food Sci Technol*. 2016;53:31–41. <https://doi.org/10.1007/s13197-015-2007-9>.
14. Sanders TH. Non-detectable levels of trans-fatty acids in peanut butter. *J Agric Food Chem*. 2001;49:2349–51. <https://doi.org/10.1021/jf001455a>.
15. Maestri D. Groundnut and tree nuts: a comprehensive review on their lipid components, phytochemicals, and nutraceutical properties. *Crit Rev Food Sci Nutr*. 2024;64:7426–50. <https://doi.org/10.1080/10408398.2023.2185202>.
16. Jeandet P, Delaunois B, Aziz A, Donnez D, Vasserot Y, Cordelier S, et al. Metabolic engineering of yeast and plants for the production of the biologically active hydroxystilbene, resveratrol. *J Biomed Biotechnol*. 2012;2012:579089. <https://doi.org/10.1155/2012/579089>.
17. Ododo A, Ojeka SO, Dapper VD. Ameliorative effect of aqueous leaf extract of *Moringa oleifera* on reproductive function following cadmium chloride induced oxidative stress in male Wistar rats. *Not Sci Biol*. 2019;11:352–7. <https://doi.org/10.15835/nsb11410485>.
18. Ovili-Odili BZ, Adienbo OM, Daubry TME, Chinko BC. Phytochemical profiling and nutraceutical benefits of methanol leaf extracts from *Datura alba* Ness. *Asian Plant Res J*. 2024;12:1–11. <https://doi.org/10.9734/aprj/2024/v12i6276>.
19. Saronee F, Amah-Tariah F, Chinko B, Dapper D. GC-MS and proximate analysis of the hydromethanol extract of *Craterispermum schweinfurthii* leaves. *S Asian Res J Nat Prod*. 2023;6:101–9.
20. Offor NN, Chinko BC. Phytochemical profiling and health benefits of chloroform and methanol extracts of *Laurus nobilis* (Bay Leaf). *Int J Biomed Mater Res*. 2025;13:10–23.
21. Pasupuleti J, Nigam SN, Pandey MK, Nagesh P, Varshney R. Groundnut improvement: use of genetic and genomic tools. *Front Plant Sci*. 2013. <https://doi.org/10.3389/fpls.2013.00023>.
22. AOAC. Official methods of analysis of AOAC international, 18th ed. AOAC International Suite 500 481 North Frederick Avenue Gaithersburg, Maryland 20877-2417, USA; 2005.
23. Trease GE, Evans WC. Pharmacognosy. 13th ed. London: Bailliere Tindall Ltd; 1989.
24. WC E. Trease and evans pharmacognosy. Nottm. Univ. Nottm; 2002, p. 21.
25. Edeoga HO, Okwu DE, Mbaebie BO. Phytochemical constituents of some Nigerian medicinal plants. *Afr J Biotechnol*. 2005;4:685–8.
26. Harborne AJ. Phytochemical methods a guide to modern techniques of plant analysis. Berlin: Springer; 1998.
27. Lorke D. A new approach to practical acute toxicity testing. *Arch Toxicol*. 1983;54:275–87.
28. Chinko BC, Amah-Tariah FS, Ekenna IC, Okpa OA. Evaluation of the effects of calabash chalk on the haematological profile of Wistar rats. *Not Sci Biol*. 2022;14:11281–11281. <https://doi.org/10.55779/nsb14311281>.
29. Singh P, Kesharwani RK, Keservani RK. 6—Protein, carbohydrates, and fats: energy metabolism. In: Bagchi D, editor. Sustainable energy enhancing human function act. Academic Press; 2017. p. 103–15.
30. Zhang Y, Zhang T, Liang Y, Jiang L, Sui X. Dietary bioactive lipids: a review on absorption, metabolism, and health properties. *J Agric Food Chem*. 2021;69:8929–43. <https://doi.org/10.1021/acs.jafc.1c01369>.
31. Barceló-Coblijn G, Murphy EJ. Alpha-linolenic acid and its conversion to longer chain n–3 fatty acids: benefits for human health and a role in maintaining tissue n–3 fatty acid levels. *Prog Lipid Res*. 2009;48:355–74. <https://doi.org/10.1016/j.plipres.2009.07.002>.
32. Yuan Q, Xie F, Huang W, Hu M, Yan Q, Chen Z, et al. The review of alpha-linolenic acid: sources, metabolism, and pharmacology. *Phytother Res*. 2022;36:164–88. <https://doi.org/10.1002/ptr.7295>.
33. Lunn J, Buttriss JL. Carbohydrates and dietary fibre. *Nutr Bull*. 2007;32:21–64. <https://doi.org/10.1111/j.1467-3010.2007.00616.x>.
34. Gunness P, Gidley M. Mechanisms underlying the cholesterol-lowering properties of soluble dietary fibre polysaccharides. *Food Funct*. 2010;1:149–55. <https://doi.org/10.1039/c0fo00080a>.
35. Gill SK, Rossi M, Bajka B, Whelan K. Dietary fibre in gastrointestinal health and disease. *Nat Rev Gastroenterol Hepatol*. 2021;18:101–16. <https://doi.org/10.1038/s41575-020-00375-4>.
36. Godswill AG, Somtochukwu IV, Ikechukwu AO, Kate EC. Health benefits of micronutrients (vitamins and minerals) and their associated deficiency diseases: a systematic review. *Int J Food Sci*. 2020;3:1–32.
37. Ojiodu CC, Akinhanmi TF, Atasie VN. Proximate analysis and physico-chemical properties of groundnut (*Arachis hypogaea* L.). *Pak J Nutr*. 2009;8:194–7. <https://doi.org/10.3923/pjn.2009.194.197>.
38. Sanni JA, Sanni GO, Awoniyi RR, Osanyinlusi R, Richards YE, Adesina GI, et al. Effects of processing on the proximate composition, mineral content and the phytochemical analysis of groundnut seeds (*Arachis hypogaea*). *Biol Med Nat Prod Chem*. 2024;13:63–71. <https://doi.org/10.14421/biomedich.2024.131.63-71>.
39. Othman RA, Moghadasian MH. Beyond cholesterol-lowering effects of plant sterols: clinical and experimental evidence of anti-inflammatory properties. *Nutr Rev*. 2011;69:371–82. <https://doi.org/10.1111/j.1753-4887.2011.00399.x>.
40. El Omari N, Bakrim S, Khalid A, Abdalla AN, Iles MAM, El Kadri K, et al. Unveiling the molecular mechanisms: dietary phytosterols as guardians against cardiovascular diseases. *Nat Prod Bioprospect*. 2024;14:27. <https://doi.org/10.1007/s13659-024-00451-1>.
41. Brufau G, Canela MA, Rafecas M. Phytosterols: physiologic and metabolic aspects related to cholesterol-lowering properties. *Nutr Res*. 2008;28:217–25. <https://doi.org/10.1016/j.nutres.2008.02.003>.
42. Poli A, Marangoni F, Corsini A, Manzato E, Marrocco W, Martini D, et al. Phytosterols, cholesterol control, and cardiovascular disease. *Nutrients*. 2021;13:2810. <https://doi.org/10.3390/nu13082810>.
43. Hilal B, Khan MM, Fariduddin Q. Recent advancements in deciphering the therapeutic properties of plant secondary metabolites: phenolics, terpenes, and alkaloids. *Plant Physiol Biochem*. 2024;211:108674. <https://doi.org/10.1016/j.plaphy.2024.108674>.
44. Siddiqui T, Khan MU, Sharma V, Gupta K. Terpenoids in essential oils: chemistry, classification, and potential impact on human health and industry. *Phytomed Plus*. 2024;4:100549. <https://doi.org/10.1016/j.phyplu.2024.100549>.
45. Hong S, Pangloli P, Perumal R, Cox S, Noronha LE, Dia VP, et al. A comparative study on phenolic content, antioxidant activity and anti-inflammatory capacity of aqueous and ethanolic extracts of Sorghum in lipopolysaccharide-induced RAW 264.7 macrophages. *Antioxidants*. 2020;9:1297. <https://doi.org/10.3390/antiox9121297>.
46. Shahidi F, Chandrasekara A. Hydroxycinnamates and their in vitro and in vivo antioxidant activities. *Phytochem Rev*. 2010;9:147–70. <https://doi.org/10.1007/s11101-009-9142-8>.

47. Chagas MdoSS, Behrens MD, Moragas-Tellis CJ, Penedo GXM, Silva AR, Gonçalves-de-Albuquerque CF. Flavonols and flavones as potential anti-inflammatory, antioxidant, and antibacterial compounds. *Oxid Med Cell Longev*. 2022;2022:9966750.
48. Maisetta G, Batoni G, Caboni P, Esin S, Rinaldi AC, Zucca P. Tannin profile, antioxidant properties, and antimicrobial activity of extracts from two Mediterranean species of parasitic plant *Cytinus*. *BMC Complement Altern Med*. 2019;19:82. <https://doi.org/10.1186/s12906-019-2487-7>.
49. Scalbert A. Antimicrobial properties of tannins. *Phytochemistry*. 1991;30:3875–83. [https://doi.org/10.1016/0031-9422\(91\)83426-L](https://doi.org/10.1016/0031-9422(91)83426-L).
50. Ortiz C, Martirosyan D. Bioactive compounds in peanuts (*Arachis hypogaea* L.): a review of their anti-inflammatory and antioxidant effects. *Agric Food Bioact Comp*. 2024;1(12):1–18. <https://doi.org/10.31989/afbc.v2i12.1525>.
51. Nunes YC, Santos GdeO, Machado NM, Otoboni AMMB, Laurindo LF, Bishayee A, et al. Peanut (*Arachis hypogaea* L.) seeds and by-products in metabolic syndrome and cardiovascular disorders: a systematic review of clinical studies. *Phytomedicine*. 2024;123:155170. <https://doi.org/10.1016/j.phymed.2023.155170>.
52. Isoje AO, Obi FO. Nutritional and phytochemical components and in vitro antioxidant capacity of raw *Arachis hypogaea* seeds. *Sci Afr*. 2023;22(3):107–14. <https://doi.org/10.4314/sa.v22i3.9>.
53. Kyei S, Eke I, Abdul-Karim H, Darko G, Akaranta O. Phytochemicals from peanut (*Arachis hypogaea* L.) skin extract with potential for pharmacological activity. *Curr Bioact Compd*. 2021. <https://doi.org/10.2174/1573407217666210202092052>.
54. Nguyen Kim TP, Thi NV, Van PT, Ngo Diem PQ, Thi Thuy DN, That QT, et al. Phytochemical constituents and determination of resveratrol from the roots of *Arachis hypogaea* L. *Am J Plant Sci*. 2013;04:2351–8. <https://doi.org/10.4236/ajps.2013.412291>.
55. Nagendra LB, Ashok P, Surana YS, Srivastava R, Madharkhandi A, Razzak AK. Immunomodulatory activity of aqueous extract of *Arachis hypogaea* seeds (Fabaceae) in rats. *Int J Pharm Sci Rev Res*. 2015;34:130–4. <https://doi.org/10.14737/journal.aavs/2016/4.9.489.493>.
56. Gul A, Khan H, Shah SI, Alsharif KF, Qahl SH, Rehman IU, et al. Pharmaceutical development of intraperitoneal *Arachis hypogaea* as a renal protective agent. *Front Biosci Landmark*. 2023;28:14. <https://doi.org/10.31083/j.fbl2801014>.
57. Liu Y, Cheng Y, Li J, Wang Y, Liu Y. Epoxy stearic acid, an oxidative product derived from oleic acid, induces cytotoxicity, oxidative stress, and apoptosis in HepG2 cells. *J Agric Food Chem*. 2018;66:5237–46. <https://doi.org/10.1021/acs.jafc.8b01954>.
58. Oppedisano F, Macri R, Gliozzi M, et al. The anti-inflammatory and antioxidant properties of n-3 PUFAs: their role in cardiovascular protection. *Biomedicine*. 2020;8:306. <https://doi.org/10.3390/biomedicine8090306>.
59. Santa-Maria C, López-Enríquez S, Montserrat-de La Paz S, Geniz I, Reyes-Quiroz ME, Moreno M, et al. Update on anti-inflammatory molecular mechanisms induced by oleic acid. *Nutrients*. 2023;15:224. <https://doi.org/10.3390/nu15010224>.
60. Wrzosek M, Zawadzka Z, Sawicka A, Bobrowska-Korczak B, Bialek A. Impact of fatty acids on obesity-associated diseases and radical weight reduction. *Obes Surg*. 2022;32:428–40. <https://doi.org/10.1007/s11695-021-05789-w>.
61. Menendez JA, Vellon L, Colomer R, Lupu R. Oleic acid, the main monounsaturated fatty acid of olive oil, suppresses Her-2/*neu* (*erbB-2*) expression and synergistically enhances the growth inhibitory effects of trastuzumab (Herceptin™) in breast cancer cells with Her-2/*neu* oncogene amplification. *Ann Oncol*. 2005;16:359–71.
62. Carrillo C. M^a del MC y SRA-T. Efecto Antitumoral Del Ácido Oleico; Mecanismos De Acción. Revisión. *Nutr Hosp*; 2012, pp. 1860–1865. <https://doi.org/10.3305/nh.2012.27.6.6010>.
63. Mancini A, Imperlini E, Nigro E, Montagnese C, Daniele A, Orrù S, et al. Biological and nutritional properties of palm oil and palmitic acid: effects on health. *Molecules*. 2015;20:17339–61.
64. Al-Rajhi AMH, Abdelghany TM, Selim S, Almuhayawi MS, Alruhaili MH, Alharbi MT, et al. Phytochemical characterization of peanut oil and its ozonized form to explore biological activities in vitro. *AMB Express*. 2025;15:76. <https://doi.org/10.1186/s13568-025-01849-x>.
65. Mar C, Lin M, Win N, Moe K. Study on fatty acids composition of four different types of peanut oil in Myanmar. *J Essential Oil Plant Compos*. 2023. <https://doi.org/10.58985/jeopc.2023.v01i03.34>.
66. Horrobin DF, Huang Y-S. The role of linoleic acid and its metabolites in the lowering of plasma cholesterol and the prevention of cardiovascular disease. *Int J Cardiol*. 1987;17:241–55. [https://doi.org/10.1016/0167-5273\(87\)90073-8](https://doi.org/10.1016/0167-5273(87)90073-8).
67. Marangoni F, Agostoni C, Borghi C, et al. Dietary linoleic acid and human health: focus on cardiovascular and cardiometabolic effects. *Atherosclerosis*. 2020;292:90–8. <https://doi.org/10.1016/j.atherosclerosis.2019.11.018>.
68. Menegazzo F, Ghedini E, Signoretto M. 5-Hydroxymethylfurfural (HMF) production from real biomasses. *Molecules*. 2018;23:2201. <https://doi.org/10.3390/molecules23092201>.
69. Pagare PP, McGinn M, Ghatge MS, Shekhar V, Alhashimi RT, Daniel Pierce B, et al. The antisickling agent, 5-hydroxymethyl-2-furfural: other potential pharmacological applications. *Med Res Rev*. 2024;44:2707–29. <https://doi.org/10.1002/med.22062>.
70. Gao H-F, Wen X-S, Xian CJ. Hydroxymethyl furfural in chinese herbal medicines: its formation, presence, metabolism, bioactivities and implications. *Afr J Tradit Complement Altern Med*. 2015;12:43–54. <https://doi.org/10.4314/ajtcam.v12i2.9>.
71. Raj PS, Bergfeld WF, Belsito DV, Cohen DE, Klaassen CD, Rettie AE, et al. Peanut glycerides. *Int J Toxicol*. 2023;42(3_suppl):79S–80S. <https://doi.org/10.1177/10915818231204277>.

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