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*Corresponding author
Dotsha Jaleel Raheem
dotsha.raheem@su.edu.krd

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Study of the phytochemical diversity of segregated *Rhus coriaria* pericarp and seeds oil and their antifungal and antibacterial activity

Dotsha Jaleel Raheem[*1], Hero Sabah Rahman[1], Nareen Qadr FaqeAbdulla[2] and Akhter Ahmed Ahmed[2]

1 Department of Chemistry, College of Science, Salahaddin University-Erbil, Erbil, Kurdistan Region, Iraq
2 Department of Biology, College of Science, Salahaddin University-Erbil, Erbil, Kurdistan Region, Iraq

ABSTRACT

Sumac fruits are used in food and as a remedy, but their seeds are often discarded as waste despite making up a large proportion of the fruit's weight. This research therefore examines the chemical composition and biological activities of oils from sumac pericarp and seeds in an attempt to find potential uses for the seeds in comparison to the long-used pericarp. Both oils were found to contain alkanes and fatty acids. The pericarp oil also contained caryophyllenes. Fatty acid methyl ester analysis revealed oleic, linoleic, palmitic, and stearic acids as major components in both parts. Pericarp oil contained more saturated fatty acids, while seed oil showed higher content of unsaturated fatty acids. The pericarp oil also contained greater amounts of total phenols, *β*-carotene and exhibited higher radical scavenging activity. Elemental analysis found K, P, Si, Cl, S, and Ca as major elements in both pericarp and seeds oil. Both oils showed moderate inhibition against *Candida albicans*. The pericarp oil strongly inhibited *Escherichia coli* and seed oil inhibited *Acinetobacter baumannii*. Moderate activity was observed against *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, and *Staphylococcus aureus* by both pericarp and seeds oil. The findings suggest both oils have potential as nutritional and antimicrobial agents.

1.Introduction

Sumac (Rhus coriaria L.) is a genus of flowering plants known for their distinctive red berries. It belongs to the family Anacardiaceae and genus Rhus. Sumac plants typically grow wildly or cultivated as shrubs or small trees, ranging in height from 1 to 10 meters depending on the species. The harvested ripe sumac berries are basically dried and ground into a coarse powder. This powder is widely used in Middle Eastern cuisine as it adds a tangy, slightly acidic flavor profile to food (Abdul-Jalil, 2020).

Sumac has been used historically in traditional medicine owing to its health benefits. It was included in the treatment of ailments such as diarrhea, ulcers, hemorrhage, wound healing, inflammation, treatment of sore throat and liver diseases (Elagbar *et al*., 2020). Investigation of aqueous and alcoholic extracts of sumac have revealed the presence of varying classes of phytochemicals including tannins, polyphenols, flavonoids, flavones, organic acids and essential oils (Karadaş *et al*., 2020; Khoshkharam *et al*., 2020; Shahrivari *et al*., 2024). Thus, due to this chemical profile, sumac is showing a broad range of biological activities including anti-microbial, anti-inflammatory, anti-oxidant, anti-diabetic and cardioprotective effects (Alsamri *et al*., 2021; Khalilpour, 2019). The unique properties of sumac fruits and diverse range of its applications have attracted a large body of research to the plant and investigation still continues regarding its chemical composition, comparison of different species and its use as a source of bioactive compounds (Karadaş *et al*., 2020; Khoshkharam *et al*., 2020).

Investigation into the oil fraction of sumac fruits has also been undertaken. The major fatty acids were found to be oleic, linoleic, palmitic and stearic acids (Kossah *et al*., 2009). The fatty acid composition was found to be mainly 18:2 (n-6) followed by 18:1 (n-9) in addition to other saturated and polyunsaturated fatty acids in much smaller proportions (Matthaus and Özcan, 2015; Morshedloo *et al*., 2022).

Studying the fatty acid composition of *R. coriaria* have been performed for the whole fruit (i.e., the pericarp and seeds together). However, sumac fruits are often used for food and culinary purposes involve using the pericarp (the edible red part of the fruit) and disposal of the seeds as waste. Fruit seeds that frequently end up as agricultural waste have a diverse chemical profile made up of lipids, proteins, carbohydrates, fibers and minerals. They also possess economic value due to richness in high-value phytochemicals (Alves *et al*., 2021).

Plant oils are rich source of nutrients and can be implemented in a diverse range of industrial, cosmetic and pharmaceutical applications (Suárez *et al*., 2021). The antifungal and antibacterial activities of plant oils have attracted considerable research interest, with promising results reported in the literature (Ornella *et al*., 2022; Petropoulos *et al*., 2021). The biological activity of extracts of sumac fruits, leaves and branches prepared in various solvents such as water, alcohol, petroleum ether and benzene have been investigated. These studies showed promising results regarding the antibacterial, antifungal, antidiabetic and anticancer activities of sumac (Alsamri *et al*., 2021; Shabbir, 2012). However, not much has been dedicated to the investigation of the plant's oil . In a study on Turkish sumac conducted by Yilmaz *et al*. (2020), sumac fruits oil was found to exhibit antimicrobial activity against the gram-negative (*E. coli,* and *P. aeruginosa*) and the gram-positive (*S. aureus*, *S. epidermidis*, and *B. subtilis*) bacterial species. The oil's biological activity was also tested against the fungus C. albicans and weak inhibition was reported.

To our knowledge, until today no records exist for chemical composition of the oil from separated sumac pericarp and seeds. Therefore, this study was performed to investigate the oil from both separated parts of seeds and pericarp of sumac in terms of fatty acid profile, antioxidant power, total phenols, *β*-carotene and elemental composition. Antibacterial and antifungal activities were also studied to determine the significance of both seed waste and fruit pericarp of sumac.

2. Materials and methods

2.1 Chemicals and reagents

Methanol (99.8%) from Chemlab, Belgium was used. Hexane, analytical grade (99%) from BIOCHEM, France. Folin-Ciocalteu's phenol reagent from OXFORD LAB FINECHEM LLP. The 2,2-Diphenyl-1-picrylhydrazyl (DPPH) reagent was from Alfa Aeser, Japan. Sodium carbonate (99.5%) from Avonchem, Macclesfield, UK. Gallic acid was from BDH, England.

2.2 Sample collection and oil extraction

Rhus coriaria fruits were sourced from the city of Akre, Kurdistan Region in the northern part of Iraq. The fruits were separated into pericarp and seeds (**Figure 1** (A and B)) using a small-scale (Nima stainless steel bowl, Japan) electrical mortar to allow

the separation of the two parts without grinding the seeds. The pericarp and the seeds comprised about 58% and 42% of the fruit's weight, respectively. Once the seeds were separated, they were ground into a fine powder using an Embleme grinder EM 100G electric mortar.

The oil was extracted from seeds and pericarp samples by mixing each part separately with *n*-hexane in a (1 g:10 mL) sample to solvent ratio. The mixture of each part was stirred for two hours, then allowed to stand overnight and filtered three times to ensure obtainment of a clear extract. The extraction process was repeated three times, the extracts were combined together and the solvent evaporated under vacuum at < 35°C. The oil yield was calculated and physical appearance of the obtained oils was noted (**Figure 1** (C and D)). The oils were refrigerated at (0–5°C) until used for analyses.

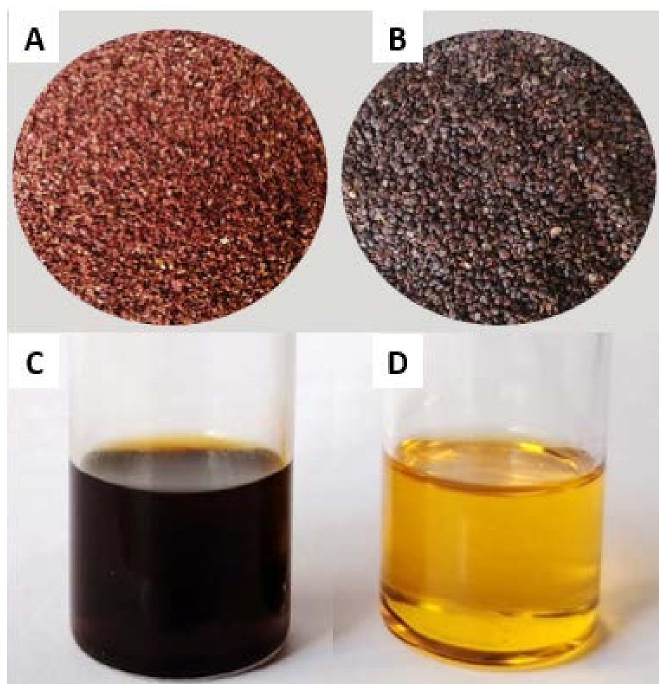

Figure 1: Sumac fruits separated into (A) pericarp (red flaky sour tasting part) and (B) seeds. (C) The oil extracted from the pericarp and (D) oil from the seeds.

2.3 Transesterification reaction

In order to prepare fatty acid methyl esters (FAME), an aliquot of 0.5 g oil was mixed with 5 mL of 3 M KOH and refluxed at 60°C for 40 minutes. The mixture was allowed to cool to room temperature and 20 mL of deionized water was added before being extracted twice with 10 mL of *n*-hexane. the extract was dried over $MgSO_4$, filtered and the solvent evaporated.

2.4 Gas chromatography–mass spectrometry (GC-MS) analysis

Oil and FAME samples were analyzed by injecting 1 *u*L into an Agilent Technologies (7820A) gas chromatogram combined with a (5977E Mass Spectrometer, USA) employing EI ionization and quadrupole mass analyzer. The chromatographic separation was achieved using an HP-5ms Ultra Inert analytical column (30 m length, 250 µm i.d. and 0.2 µm film thickness). Splitless sample injection mode was applied and helium 99.99% was used as a carrier gas. Both injector and inlet temperatures were maintained at 250°C. The oven temperature program was set as follows: an initial temperature of 60°C was held for 3 min, then raised to 180°C at a rate of 7°C/min, then to 280°C at a rate of 8°C/min and held at this temperature for 5 min at the end of the run. For the mass detector, a scan range of m/*z* 25–1000 was applied. Chromatographic peaks were identified by comparing their spectral features with NIST 11 spectral library. Only peaks with quality factors of more than 70% were reported. Other peaks that belonged to industrial contaminants and those due to column bleeding were neglected.

2.5 Preparation of methanolic extract of the oil

In a sample tube, 0.5 g of the oil (from either seeds or pericarp) was taken and dissolved in 1 mL of *n*-hexane. Then 5 mL of methanol was added and the tube was capped and mixed using a vortex mixer (Whirlimixer from Fisons Scientific Equipment, UK) for 3 min to form a cloudy suspension. The resulting mixture was then centrifuged on 5000 rpm for 10 min using a (HermleZ200A) Benchtop centrifuge to allow the complete separation of the upper methanol layer from the hexane layer (oil portion). This process and the subsequent total phenolic and radical scavenging activity tests were broadly based on the method described by Molole *et al.* (2022). However, sample to solvent ratios, time and quantities were modified to better suit the nature of our samples and their contents of phenolics and antioxidants.

2.6 Total phenolic content

In a test tube, 300 µL of the oil methanolic extract was taken and 100 µL of Folin-Ciocalteu reagent was added to it. The contents of the tube were mixed and allowed to stand for 2 min before the addition of 100 µL of (7.5%) Na_2CO_3 solution and

making up the total volume to 2500 uL with deionized water. The reaction mixture was allowed to stand at room temperature in the dark for 60 min. Following which, the absorbance was read on an (EMC-11S-UV - visible spectrophotometer) at 725 nm against a blank of methanol-water in similar ratios to what has been used in the reaction mixture. A series of gallic acid standards (0.01–0.1 mg/mL) was used to construct the calibration curve (y = 10.863x + 0.2423 with R^2 = 95.1%) and the results were expressed as gallic acid equivalent in milligrams of total phenols in a gram of oil.

2.7 2,2-Diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity

This test was performed differently for the pericarp and seed oils in terms of oil concentration used in the test. For the pericarp oil, a series of different sample aliquots (100, 75, 50, 25 and 12.5 µL) were mixed with 1000 µL of (0.406 mM) DPPH reagent in methanol and the reaction mixtures were made up to 3000 µL with the same solvent. For the seed oil on the other hand, a serial dilution consisted of (1250, 1000, 750, 500 and 250 µL) was used and the reaction mixtures were also made up to 3000 µL final volume. This difference in volumes used for the two oil types was established based on optimizing reagent response to different concentration ranges for both types of oils.

A control was prepared along with the samples in each set by mixing the 1000 µL of the reagent with 2000 µL methanol. The tubes were allowed to stand at room temperature in the dark for 30 min. After which, the absorbance was read at 517 nm against a blank of methanol. A calibration curve (y = -13.874x + 1.4735, R^2 = 99%) constructed using gallic acid as a standard antioxidant in the range (0.025–0.1 mg/mL). DPPH percentage scavenging effect was calculated applying the formula:

$$\text{DPPH scavenging effect } \% = \left(\frac{A_{\text{control}} - A_{\text{sample}}}{A_{\text{control}}}\right) \times 100$$

Where $A_{control}$ and A_{sample} are absorbance of control and samples, respectively. Half-maximal inhibitory concentration (IC 50) was calculated by plotting DPPH scavenging effect % against the different sample concentrations and finding the concentration equivalent to 50% scavenging activity applying the equations (y = 0.7152x + 24.046, R^2 = 100%) for pericarp oil and (y = 0.0894x - 15.627, R^2 = 99.9%) for the seeds oil.

2.8 Analysis of *β*-Carotene

The amount of 0.5 mL of the pericarp oil (or 2 mL of the seeds oil) was dissolved in 8 mL n-hexane and the absorbance of the resulting solution was measured at 450 nm against a blank of hexane. Beer-Lambert's law was applied for the calculation of the results:

$$C = \frac{A}{\varepsilon L}$$

Where, C: is the concentration in mol/L, A is the absorbance, ε is the extinction coefficient for β-carotene in n-hexane (2592 L/(mol·cm) and L is the path length (1 cm). The concentration was then converted to units of g/L by multiplying by the molar mass of β-carotene (536.87 g/mol). Analysis of β-carotene by this method depends on the presence of a maximum absorption at 450 nm in n-hexane. Other carotenes including the α- and γ- isomers also exhibit absorption at the wavelength range of (400–500 nm), but to lower extents (Rodriguez-Amaya, 2001). Therefore, the results might also be including minor contribution of other carotene isomers if present in the oil.

2.9 X-Ray Fluorescence Spectroscopy (XRF) elemental analysis

Elemental analysis was performed using a Rigaku NEX CG X-ray Fluorescence Spectrometer equipped with a set of interchangeable targets (RX9, Mo, Cu, and Al). The spectrometer operates in a Cartesian Geometry (CG) configuration, enhancing sensitivity and accuracy for light and heavy element detection. Vegetable oil samples were homogenized and then pipetted into polypropylene XRF sample cups. Measurements were conducted under helium gas to enhance the detection of the lighter elements such as sulfur and phosphorus. The data were processed using RPF-SQX Fundamental Parameters (FP) software.

2.10 Antifungal activity

2.10.1 Media preparation

A) Sabouraud Dextrose Agar (SDA): Prepared by mixing 63 grams of SDA powder with one liter of distilled water (D.W.), the medium was autoclaved for 15-20 min at 121°C and a pressure of 15 pounds/inch^2. After sterilization, 0.05 gm of chloramphenicol and 0.5 gm of cycloheximide were added to the medium, to inhibit the growth of bacteria and non-dermatophytes fungi, respectively. This

medium was used to grow dermatophytes.

B) Sabouraud Dextrose broth (SDB): Prepared by dissolving 10 g peptone and 40 g dextrose in 1 liter of D.W., sterilized by autoclave. Then chloramphenicol and cycloheximide were added. This medium was used to activate and preserve dermatophytes.

C) Potato Dextrose Agar (PDA): Prepared by dissolving 39 g of PDA powder in 1 liter of D.W., sterilized by autoclave, then chloramphenicol was added. This medium was used for the growth of non-dermatophyte fungi.

D) Brain Heart Infusion Broth (BHI): Prepared by dissolving 52 g of BHI in 1 liter of D.W., then sterilized by autoclave and used to activate fungi.

2.10.2 Antifungal sensitivity test of oil extracts by agar well diffusion method (AWDM)

The oil extracts were tested for their antifungal activity against pathogenic fungi sourced from human patients. The inoculum of fungal species was prepared using 10 days of incubation at 37°C for dermatophytes: *Trichophyton* sp., *Microsporum* sp. and *Epidermophyton* sp. on Sabouraud dextrose broth (SDB), 5 days of incubation at 25°C for *Aspergillus niger* and 48 hr of incubation at 37°C for *Candida albicans* on (BHI) broth and they were adjusted to ($1x10^6$/mL) with a bright line hemocytometer (Hausser Scientific, Horsham, Pa) (Aboualigalehdari *et al*., 2016). Briefly, for dermatophytes and *C. albicans*; 100 µL suspension was spread over SDA, while for *A. niger* 100 µL was spread over PDA. The culture medium was punctured using a sterile corkborer to create wells with a diameter of 6 mm. Then, each well was filled with 100 µL of each oil extract and control until it was completely full. The treated plate was incubated, for dermatophytes at 37°C for 10-15 days, *C. albicans* at 37°C for 48 hr., while *Aspergillus niger* at 25°C for 5-7 days. Millimeters were used to measure the widths of the zones of inhibition (Aibinu *et al*., 2007; Srinivasan *et al*., 2001).

2.11 Antibacterial activity

2.11.1 Bacterial strains

Clinical isolates of *Acinetobacter baumannii, Escherichia coli, Klebsiella pneumoniae, Pseudomonas aeruginosa* and *Staphylococcus aureus* were selected to determine the antibacterial effect of both pericarp and seed oils. The bacterial species were obtained from clinical specimens (sputum, urine, blood, and pus from wounds), submitted for bacteriology tests from patients admitted to the hospitals in Erbil city, Iraq. Each bacterial isolate was activated in nutrient broth (Oxoid, UK) at 37℃ for 18-24 hours then appropriate dilution was performed as required.

2.11.2 Determination of antibacterial activity

The antimicrobial effect of both sumac oils was assessed via well-diffusion technique (Valgas *et al*., 2007). The turbidity of the overnight of the bacterial cultures was adjusted to 0.5 McFarland (OD adjusted to 0.5 at 550 nm) and plated onto Mueller Hinton Agar plates. Then, 6 mm wells were bored and 150 µL of the oils was placed into the wells. Following this, the plates were placed in the incubator for 24 hours at 37ºC. A ruler was employed to measure the diameter of the formed inhibition zones around the wells.

3. Results and Discussion

As shown in **Figure 1** and **Table 1**, the two oils have different physical and chemical characteristics. The pericarp oil showed dark red-brown color while seeds oil revealed clear-yellow appearance. Additionally, the pericarp oil exhibited solid – liquid consistency and tended to solidify easily as temperature drops in comparison to the seeds oil's yellow color and tended to remain liquid at both room temperature and upon refrigeration. An oil's physical state is mainly a reflection of its fatty acid composition. The presence of saturated fatty acids allows easier stacking of fatty acid chains and thereby resulting in oils with higher melting points, while the presence of unsaturated fatty acids particularly in the *cis*- orientation results in oils with lower melting points (Domínguez *et al*., 2022).

3.1 Gas – liquid chromatographic analysis

Gas chromatographic analysis of the oils revealed the presence of saturated, unsaturated fatty acids and alkanes (**Figure 2** and **Table 2**). The short- and medium-chain fatty acids, such as valeric and octanoic acid, were found in both pericarp and seeds oil samples. Longer chain fatty acids including palmitic acid, stearic, oleic and linoleic acids were also found either in their free or esterified forms. Very long chain fatty acids (>18C) such as eicosanoic acid were also detected. The presence of such long-chain fatty acids in plants is found as part of the cuticle wax which works to protect the plant from desiccation and harsh external conditions (Zhukov and Shumskaya, 2020).

Compounds belonging to the caryophyllene family of bicyclic sesquiterpene were detected in the

pericarp oil. These included *α*- and *β*-caryophyllene, *β*-caryophyllene oxide and *δ*-cadinene. This is in agreement with the results presented by Shahrivari *et al*. (2024) that reported the presence of similar compounds in the essential oil fraction of sumac varieties from Kurdistan region of Iraq. Caryophyllene compounds have been found in many plants including varieties of hemp (*Cannabis sativa* L.). They have been associated with a range of useful biological effects including pain relief, anti-cancer with positive effects on arthrosclerosis and nervous system diseases (Francomano *et al*., 2019).

Transesterification of the fatty acids and glycerides in the oils yielded fatty acid methyl esters (FAME)s (**Figure 3)**. Fatty acids and their ratios listed in **Table 3**. Total unsaturated fatty acids (TUFA)s was more abundant in comparison to saturated fatty acids (SFA)s where TUFAs comprised (61.11%) and (76.73%) of the pericarp and seeds oil, respectively; which, in turn, the ratios of SFAs in the pericarp and seeds oil were (38.89%) and (23.24%), respectively. The ratios for pericarp oil are comparable to those reported by Kossah *et al*. (2009) for Syrian sumac.

Table 1. Comparative physical and chemical properties of sumac pericarp and seed oils.

0.6	Pericarp oil	Seeds oil
Color	Redish-brown	Clear yellow
Oil yield %	8.5	8.4
Physical state	Semi-solid at room temperature, solidifies upon refrigeration	Liquid at room temperature, remains liquid upon refrigeration
Total phenols (mg/g) GAE	3.32 ± 0.04	0.80 ± 0.01
DPPH radical scavenging effect (IC50) (mg/L)	36.3	734.1
β-Carotene (mg/L)	800.8 ± 12.0	147.1 ± 2.3

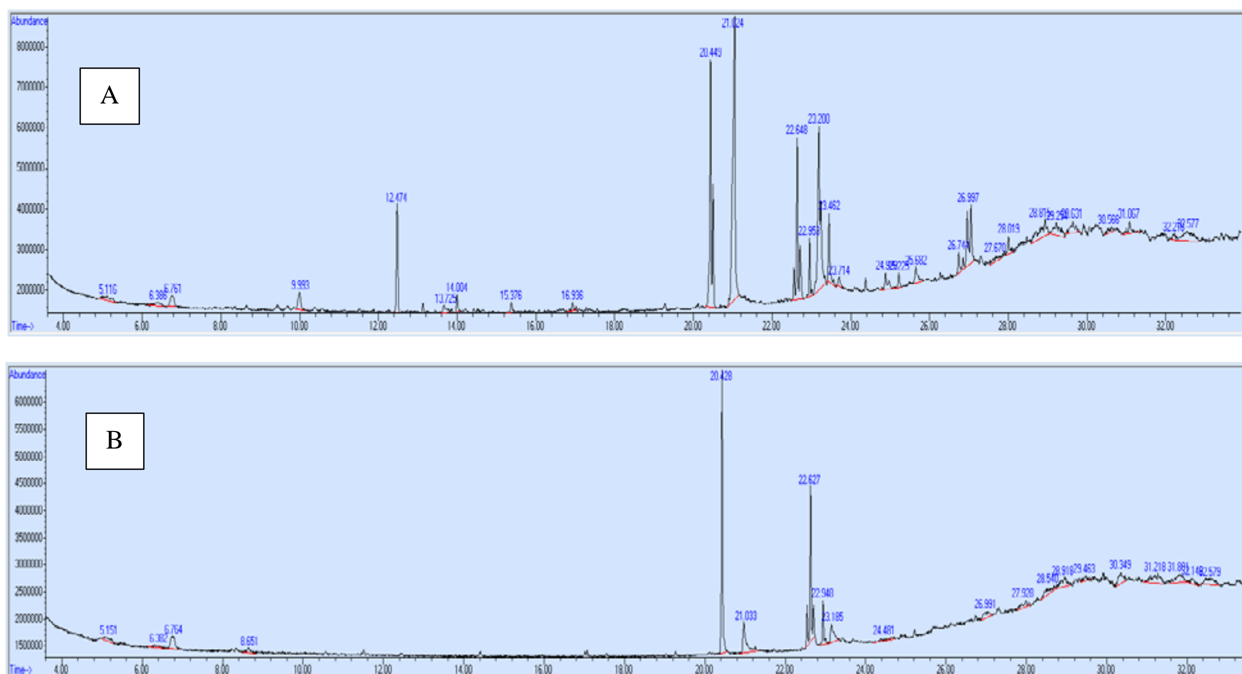

Figure 2: GC-MS oil profile of (A) Sumac fruit pericarp and (B) sumac seeds

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Table 2. Chemical compounds identified by GC-MS analysis of sumac pericarp and seed

	Compound name	t_R	Molar mass	Molecular formula	Area %	
					Pericarp oil	Seeds oil
1	Valeric acid	5.10	102.13	$C_5H_{10}O_2$	1.57	2.05
2	Methyl octanoate	6.76	158.24	$C_9H_{18}O_2$	1.79	6.03
3	β-Caryophyllene	12.48	204.36	$C_{15}H_{24}$	5.81	-
4	Humulene (α-caryophyllene)	13.12	204.36	$C_{15}H_{24}$	0.53	-
5	*δ*-Cadinene	14.01	204.35	$C_{15}H_{24}$	0.31	-
6	Caryophyllene oxide	15.37	220.35	$C_{15}H_{24}O$	0.32	-
7	Methyl palmitate	20.45	270.45	$C_{17}H_{34}O_2$	19.79	36.21
8	Palmitic acid	21.03	256.43	$C_{16}H_{32}O_2$	28.55	10.11
9	(*Z,Z*)- 9,12-Octadecadienoic acid methyl ester (methyl linoleate)	22.58	294.47	$C_{19}H_{34}O_2$	1.36	3.21
10	(*Z*)- 9-Octadecenoic acid methyl ester	22.65	296.49	$C_{19}H_{36}O$	8.79	20.80
11	(*Z*)-11-Octadecenoic acid methyl ester	22.75	296.49	$C_{19}H_{36}O$	2.70	3.22
12	Methyl stearate	22.95	298.5	$C_{19}H_{38}O_2$	2.97	6.10
13	(*Z*)-Octadec-9-enoic acid (oleic Acid)	23.20	282.46	$C_{18}H_{34}O_2$	19.15	5.99
14	Stearic acid	23.46	284.48	$C_{18}H_{36}O_2$	4.42	4.67
15	Eicosanoic acid methyl ester	25.23	326.557	$C_{21}H_{42}O_2$	0.83	1.61
16	17-Pentatriacontene	27.68	490.93	$C_{35}H_{70}$	1.11	-

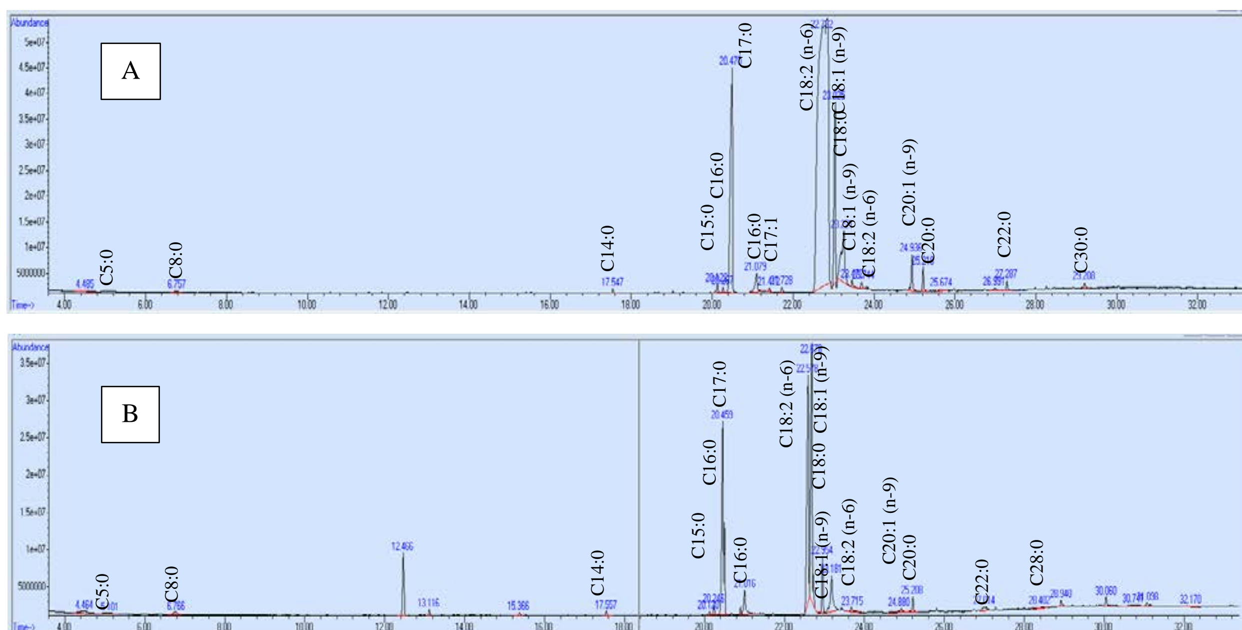

Figure 3: GC-MS chromatogram with annotated fatty acids and FAMEs for (A) Sumac fruit pericarp oil and (B) Sumac seeds oil.

However, the seed oil showed higher TUFAs and lower amounts of SFAs which explains the higher fluidity of the seeds oil compared to the pericarp oil that tends to be semi-solid at room temperature and

solidifies easily upon slight cooling (**Table 1**). There is also a good agreement between the ratios of the individual fatty acids including myristic, palmitic, stearic, oleic and linoleic with Syrian sumac. However, the presence of palmitoleic (C16:1) and linolenic (C18:3) were also reported in small amounts in Syrian sumac which was not found in the studied sumac samples. Reports on Turkish sumac samples by Matthaus and Özcan (2015) showed some differences in the oil composition, for instance, lower ratio of (C16:0) ranging from (6-9 %) was reported compared to its ratio in pericarp (29.81%) and seed oils (14.64%). Their samples also contained lower amounts of (C18:1(n-9)) at about (26.3-28.9 %) compared to
(34.4% and 34.1%) for the pericarp and seeds oil and higher amounts of (C18:2 (n-6)) at about (58.6-61.6%) compared to (26.13% and 41.03%) for the pericarp and seed oils respectively. Additionally, they reported the presence of small amounts (area% <1) of (C18:3) in 4 out of 10 sumac samples in the study and (C18:4) in all their samples which were not detected in this study. Similar comparison can be made with other Turkish sumac oil samples investigated by Karadaş *et al.* (2022) and Yilmaz *et al.* (2020) who reported values of (C18:0) ranging from (2.1-3.3%) and (C18:1) of (42.2-43.4%) and (C18:2) ranging from (25.2-30.3%). However, their samples contained higher amounts of (C16:0) ranging from (18.4-22.2%) which was close to its value in the seeds oil. Iranian samples studied by Nayebpour and Asadi-Gharneh (2019) showed that the major fatty acid was also (C18:1) ranging between (36.7-44.7%) followed by (C18:2) at (22.7-33.5%) and.

Table 3. Fatty acid composition of sumac pericarp and seed oils.

			Area %	
	Compound name	Carbon chain	Pericarp	Seeds
1	Valeric acid	C5:0	0.52	0.12
2	Octanoic acid	C8:0	0.73	0.14
3	Myristic acid	C14:0	0.41	0.15
4	Pentadecanoic acid	C15:0	0.37	0.34
5	Palmitic acid	C16:0	29.81	14.64
6	Heptadecanoic acid	C17:0	0.80	0.15
7	*cis*-10-Heptadecenoic acid	C17:1	-	0.14
8	Stearic acid	C18:0	4.24	6.49
9	*cis*-11-Octadecenoic acid (cis-Vaccenic acid)	C18:1	0.25	0.23
10	Oleic acid	C18:1 (n-9)	34.37	34.11
11	Linoleic acid	C18:2 (n-6)	26.13	41.03
12	Eicosanoic acid	C20:0	1.46	0.70
13	*cis*-11-Eicosenoic acid	C20:1 (n-9)	0.36	1.22
14	Docosanoic acid	C22:0	0.24	0.33
15	Octacosanoic acid	C28:0	0.31	-
16	Melissic acid	C30:0	-	0.18
	SFA		38.89	23.24
	MUFA		34.98	35.7
	PUFA		26.13	41.03
	TUFA		61.11	76.73
	TUFA/SFA		1.57	3.30
	Total		100	100

(C16:0) at (21.4-29.8%) and finally (C18:0) at (2.3-3.6%). Almost all of the studies show that (C18:1) is the major fatty acid followed by (C18:2) and (C16) which is found in either similar or slightly lower quantities than (C18:2). These ratios are close to the results regarding pericarp oil, but different from that of the seeds oil where (C18:2 (n-6)) is the major fatty acid followed by (C18:1 (n-9)) then (C16:0) at much lower quantity

The oils' content of saturated and unsaturated fatty acids can have both positive and negative health implications. The presence of higher ratios of saturated fatty acids such as palmitic acid is associated with elevated levels of low density lipoprotein (LDL) and increased risk of cardiovascular diseases. Oleic acid on the other hand, is known for its rather beneficial effects such as elevating the symptoms of type 2 diabetes, inflammatory diseases and cancer. Linoleic acid is an essential fatty acid which is necessary in moderation, but excessive intake leads to inflammation and increased mortality risk (Liput *et al*., 2021). Despite the seed oil containing high ratios of TUFA/SFA (3.3) that indicate more beneficial health effects, however, it may have the disadvantage of being less stable and more prone to oxidative damage in comparison to the pericarp oil which contains lower ratio of TUFA/SFA (1.57).

Fatty acids that have not been reported before are the C17:1 fatty acid (*cis*-10-Heptadecenoic acid) in the seeds oil and the C28:0 (octacosanoic acid) in the pericarp oil. Additionally, a long chain C30:0 fatty acid was only identified in the seeds oil.

3.2 Total phenols, *β*-carotene content, and radical scavenging activity

Total phenols and *β*-carotene content of the pericarp oil were found to be (3.32 ± 0.04 mg/g) and (800.8 ± 12.0 mg/L), which were much higher than that of the seeds oil of (0.80 ± 0.01 mg/g) and (147.1 ± 2.3 mg/L), respectively (**Table 1**). Phenolic compounds and carotenes contribute to the ability of the plant extract to withstand oxidative damage (Blasi and Cossignani, 2020). This can be easily realized from the low IC50 value (36.3 mg/L) in pericarp oil in comparison to that of the seeds oil (734.1 mg/mL). A previous work on whole sumac fruit oil by Karadaş *et al*. (2022) reported higher values of total phenols at (14.7 mg/g) and a value of (84.93 mg/mL) for DPPH radical scavenging activity.

Half-maximal inhibitory concentration (IC 50) is the amount of the an antioxidative substance needed to inhibit 50% of DPPH free radical. Lower IC50 values indicate higher radical scavenging activity of the sample. Based on these results, and combined with the fact that the pericarp oil has lower content of TUFA and PUFA, it could be concluded that it is the oil portion with the higher oxidative stability compared to the seeds oil that contain higher ratio of unsaturated fatty acids and lower ratio of the phenolic and carotene antioxidants (Blasi and Cossignani, 2020; Jabbar *et al*., 2023).

3.3 Elemental analysis

Elemental analysis using X-ray fluorescence revealed the presence of phosphorus (P), potassium (K) and silicone (Si) as the major elements in the pericarp oil. All the elements present in the pericarp oil were also found in the seeds oil at lower or similar levels were except bromine (Br), potassium (K) and titanium (Ti) which were absent in seed oils, but on the other hand, seed oils contained hafnium (Hf) and tantalum (Ta) which were not detected in pericarp oils (**Table 4**). None of the toxic heavy metals such as cadmium (Cd), lead (Pb), Arsenic (As) and antimony (Sb) were detected. However, copper (Cu) was found in concentrations of (2.14 and 1.55 ppm) in the pericarp and seeds, respectively which is higher than the recommended levels. Highest permissible levels for copper in refined fats and oils is (0.1 mg/kg), in virgin fats and oils is (0.4 mg/kg) and cold presser fats and oils is (0.4 mg/kg) (FAO-WHO, 2023). These levels were also higher than those reported for vegetable oils extracted from olive, sunflower, mustard, linseed and rapeseed ranging from 0.025-0.83 ppm (Ashraf, 2014; González-Torres *et al*., 2023). Iron level (Fe) was within the limits set by the Codex Alimentarius levels for International Food Standards for refined (2.5 mg/kg), virgin (5.0 mg/kg) and cold-pressed fats and oils (5.0 mg/kg) (FAO-WHO, 2023). Iron content was in the lower end of the range reported for food plants (1 – 218 ppm) and comparable to its concentration in carrots and sunflowers (Ashraf, 2014). The concentration of zinc (Zn) was in agreement with previously reported values for pure and blended vegetable oils (Manzoor *et al*., 2018).

The concentration of (Ti) was within the range for food plant (0.13-6.7 ppm), while (Hf) and (Ta) concentrations were higher than their values reported for food (0.6-1.1 ppb) and non-food (1-6 ppb) plants (Ashraf, 2014).

3.4 Antifungal and antibacterial activity

The ability of the studied oil extracts to reduce or inhibit the growth of fungal genera: *Aspergillus niger, Candida albicans, Epidermophyton* sp.,

Microsporum sp. and *Trichophyton* sp. were tested by Agar Well Diffusion Method. **Table 5** lists all five genera of fungi on SDA agar supplemented for dermatophytes and *Candida* sp., and *Aspergillus niger* on PDA. In general, all genera were resistant for oil extracts, except *Candida albicans* which exhibited moderate inhibition for both oils. This is in agreement with previous reports of aqueous and alcoholic extracts of *Rhus coriaria* that indicated inhibitory activity against *C. albicans* (Alsamri *et al*., 2021; Yilmaz *et al*., 2020).

Table 4. Elemental composition of Pericarp and seeds oil based on XRF analysis.

Elements	Pericarp oil (ppm)	Seed oil (ppm)
Br	0.617	-
Ca	31.2	19.6
Cl	54	47.2
Cu	2.14	1.55
Fe	3.32	3.79
Hf	-	1.56
K	100	-
P	105	18.4
S	44.2	22.8
Si	96.6	271
Ta	-	1.51
Ti	1.52	-
Zn	1.07	1.37

Both sumac pericarp and seed oils showed antibacterial activity against the tested bacterial strains (**Table 5**). The pericarp oil showed higher inhibitory effect compared to seeds oil on *E. coli* at (23.7 ± 0.9) versus (13.7 ± 0.9), while the seeds oil showed higher activity against *Acinetobacter baumannii* at (24.3 ± 0.7) compared to pericarp oil (12.3 ± 0.3). Both oils showed relatively equal and moderate activity against *Klebsiella pneumoniae*, *Pseudomonas aeruginosa* and *Staphylococcus aureus*. Previous studies have also reported antibacterial activity of whole sumac fruit oil against *Staphylococcus* bacteria that were found to be higher than that of penicillin and showed low to moderate activity against *E. coli* (Shahrivari *et al*., 2024). Similar activity has been reported for ethanolic, ethyl acetate, hydroalcoholic and essential oil extracts of sumac fruits against *A. boumannii*, *E. coli* and *S. aureous* (Alsamri *et al*., 2021).

The richness of sumac extracts in phenolic compounds including tannins, flavonoids, and phenolic acids is the major driver for its antimicrobial activity. These compounds cause disruption of the microbial membrane and cell walls by affecting enzymes that regulate their synthesis (Rashid *et al*., 2018, 2016; Rayne and Mazza, 2007). In addition to organic acids such as malic, succinic and phloroglucinol, two compounds have been assigned as the main antibacterial agents.

Table 5: Inhibitory activity of the oil extracts on the development of some pathogenic fungi and bacteria

	Diameter of inhibition zone (mm) ± SEM	
Fungal genera	Pericarp oil	Seeds oil
Aspergillus niger	0	1
Candida albicans	8 ± 0.2	9 ± 0.2
Epidermophyton sp.	0	0
Microsporum sp.	0	1 ± 0.0
Trichophyton sp.	3 ± 0.0	4 ± 0.2
Bacteria species		
Acinetobacter baumannii	12.3 ± 0.3	24.3 ± 0.7
Escherichia coli	23.7 ± 0.9	13.7 ± 0.9
Klebsiella pneumoniae	12.7 ± 1.2	11 ± 0.6
Pseudomonas aeruginosa	14.7 ± 0.9	15.7 ± 0.3
Staphylococcus aureus	11.8 ± 0.2	10 ± 1.5

These compounds are the diketones (2,5-furandione) identified by Rashid *et al*. (2016) in the aqueous extract and (1,2-dioxo-6-hydroxycyclohexadiene-4-carboxilic acid) isolated by Ahmadian-Attari *et al*. (2016) from the ethyl acetate extract of sumac. The studies concerning bioactive compounds in sumac mostly targeted extracts prepared using solvents of rather high polarity including water, methanol and/or ethanol, water-ethanol extracts (Rayne and Mazza, 2007). Investigation into the nonpolar hexane extract's structure-activity relationship has yet to be explored.

4. Conclusion

Sumac pericarp and seed oils display distinct physical and chemical properties. The pericarp oil exhibited higher levels of total phenols, carotene, and stronger radical scavenging ability, making it superior in these aspects. Both oils, however, are rich in nutritionally important fatty acids and essential elements, with unique fatty acids such as *cis*-10-heptadecenoic acid (C17:1) in the seeds oil and octacosanoic acid (C28:0) in pericarp oil identified for the first time. Both oils demonstrated antibacterial activity, with notable differences against some of the tested species, including stronger efficacy of pericarp oil against *E. coli* and seed oil against *A. baumannii*. Moderate antifungal activity was found on *C. albicans*, but not against filamentous fungi. These findings highlight the potential of both the edible pericarp and the typically discarded seeds for further nutritional and biological research, as well as their possible applications in food and pharmaceutical industries.

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Conflict of interest

The authors declare no conflict of interest.

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