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Research Article

Bioactivity of Sumac (*Rhus Coriaria*) Extract as a Green Alternative for Plant Pathogen Inhibition

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Abstract: Environmental stress caused by pathogenic fungi leads to considerable losses in global crop productivity. Plant-derived extracts are eco-friendly and sustainable alternatives that can inhibit biotic stresses. Sumac (*Rhus coriaria*) is widely used in industrial and medicinal applications due to its extract rich in secondary metabolites, similar to those found in chemical pesticides and pharmaceuticals. This study aimed to characterize the phytochemical composition of sumac seed extract using GC–MS analysis and evaluate its bioactive potential in suppressing major fungal pathogens of crops. GC–MS identified multiple compounds, including eneicosane, ethyl phthalate, tetratriacontane, eicosane, docosane, heptacosane, 5,6-benzoquinoline, silicic acid, diethyl bis (trimethylsilyl) ester, oxasiloxane, and hexadecamethyl derivatives. The inhibitory activity of various concentrations of the aqueous seed extract was tested against *Aspergillus* spp., *Pythium aphanidermatum*, and *Fusarium oxysporum*. All concentrations showed antifungal activity, with the highest inhibition observed at 100% extract concentration. *Aspergillus* spp. were more sensitive to the extract than *F. oxysporum* and *P. aphanidermatum*. The 100% extract exhibited strong inhibitory effects on all tested pathogens. Overall, the findings demonstrate significant antimicrobial potential of sumac seed extract, attributable to its diverse bioactive constituents.

Keywords: Biotic stress, Sumac extract, Bio fungicides, green synthesis, low-input farming system

Introduction

Environmental stress is an external negative factor that delays plant growth and development (Abdelkader *et al*., 2022). It is classified into abiotic and biotic stress. Biotic stress happens as a result of living organisms such as fungi and bacteria invading plants (Zargar *et al*., 2020; Masri and Kiss, 2023). This invasion may result in damage to the plants. Fungal pathogens can cause significant crop losses, which can affect the world's food supply chain (Zubrod *et al*., 2019). The application of frequent fungicides is done during planting season and post-harvest processes to stop the actions of fungi which leads to deterioration of fruits and vegetables (Sharma *et al*., 2019). Over the past decade, there has been an increase in the use of fungicide, with approximately 400,000 tons applied globally, making up 17.5% of global pesticide applications. Additionally, there has been increasing concern about the harmful effects of chemical pesticides (Shakouri *et al*., 2012; Bayat and Zargar, 2020). Human health, biodiversity, resource consumption, and environmental pollution are influenced directly as a result of fungicide application, which has important sustainability effects. Although pesticides are economically valuable due to their toxic qualities, but they also significantly threaten sustainability. Many previously common pesticides are banned due to their detrimental effects on the ecosystem by increasing toxicity to humans and the environment.

Soil-borne fungi plant pathogens are the most common microorganisms in soil and cause infections in plants. They complete their life cycles either in the soil or partially on plant surfaces (Koike *et al*., 2003). Fusarium spp., Rhizoctonia solani, Pythium spp. and Sclerotium rolfsii are some of the soil-borne pathogenic fungi that affect the yield and quality of harvested crops, reduce overall

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productivity, and these infections can persist in soil for a long time (Ploetz, 2007).

Biofungicides provide an optimal approach for plant disease control. They are a non-chemical and eco-friendly way to manage plant diseases, avoiding many of the problems associated with chemical fungicides (Feeny *et al.*, 1969). There are two main types of biofungicides: microorganism-based pesticides and plant-based-product pesticides. Biofungicides offer an environmentally friendly alternative that mitigates many negative effects of chemical pesticides (Sheir *et al.*, 2015). Green chemistry focuses on extracting bioactive substances from various plant parts (Abbey *et al.*, 2019; Brown *et al.*, 2019). The main advantages of this method include producing more available biomass with low environmental impact and reducing environmental toxicity. Green synthesis has gained popularity due to the use of plant extracts containing biomolecules instead of hazardous synthetic chemicals (Aygun *et al.*, 2023; Göl *et al.*, 2020).

Rhus coriaria L., commonly known as sumac, belongs to the family Anacardiaceae. It is valued for its strong antimicrobial properties. This edible medicinal herb is native to Mediterranean regions and is commonly used as a culinary spice. The seeds form the primary edible portion consumed by humans (Abdul-Jalil, 2020). Sumac is the only indigenous species of the *Rhus* genus in Iraq. The genus is naturally distributed throughout the Mediterranean region, North Africa, Iran, the Caucasus, and Central Asia (Khaula and El Sami, 2020). Some believe the word “sumac” is derived from the Syrian word *Sumaga*, meaning “red” (Nasar-Abbas and Halkman, 2004).

The bioactivity of Sumac, has emerged as a promising green alternative for the inhibition of plant pathogens, with significant implications for sustainable agricultural practices. Sumac extract is rich in bioactive compounds such as phenolic acids, tannins, and flavonoids, which possess potent antimicrobial and antioxidant properties. These characteristics not only contribute to the health benefits of sumac in human diets but also enhance its potential as a natural biocontrol agent in agriculture, particularly as an alternative to chemical pesticides (Emanet *et al*., 2022).

More than 200 compounds from the sumac plant have been identified and characterized, mostly associated with medicinal active compounds (Abu-Reidah *et al*., 2014). Some of these chemical compounds include several phenolic compounds, which are of medical importance, as sumac contains approximately 15–20% polyphenolic compounds, which are mostly classified as tannins (Taskin *et al*., 2020). Except for the presence of small amount of gallic acid, which is a simple phenolic compound (Van Loo *et al*., 1988), Sumac contains important phenolic compounds such as 4-methoxy-3,5-dihydroxybenzoic acid and methyl gallate (Rayne and Mazza, 2007).

According to their chemical structure, phenolic compounds are separated into a number of subgroups, including lignans, quinones, curcuminoids, coumarins, flavonoids, tannins, stilbenes, phenolic acids, and simple phenols (Gan *et al*., 2019; Shavandi *et al*., 2018). These compounds exhibit many biological activities, including antiviral, antifungal, antibacterial, and antioxidant actions. Consequently, phenolics are potential therapeutic agents for treating diabetes, cancer, cardiovascular disorders, neurodegenerative diseases, inflammatory conditions, and aging-related issues (Arif *et al*., 2009; Brglez Mojzer *et al*., 2016; Hahn and Bae, 2019; Jiang and Dusting, 2003).

The simple phenolic compound is one of the secondary metabolic compounds that plants produce. It comprises one aromatic ring to which one or more groups are attached of the hydroxyl groups (OH). This group carries OH-Aggregates with antimicrobial properties (General, 2001; Zhang and Tizard, 1996).

Phenolic compounds precipitate proteins in the bodies of bacteria by forming hydrogen bonds between hydroxyl groups. Phenolic acids bind to proteins, causing a disruption in the function of some essential and necessary enzymes in the bodies of these bacteria (Reed, 1995) Certain phenolic compounds interact with structural proteins in bacterial and fungal cell walls, as well as with membrane enzymes in fungal cells, leading to the degradation of the wall or membrane (Cowan, 1999). Sumac contains many antioxidants, which reduce damage resulting from oxidative stress in the body and protect cells from damage. Below are some antioxidants and biologically active compounds in the sumac plant that benefit it (Shidfar *et al*., 2014). Bacteria and fungi have gained resistance due to previous dependence on copper-based insecticides and fungicides. Additionally, they damage the soil by eradicating important soil bacteria and gradually degrading it (Bahki and Khan, 2001). This circumstance has led to the pursuit of novel approaches that are less detrimental to the environment. Plant extracts are used in this way because they include a variety of secondary metabolites that are less expensive and more ecologically friendly than chemical pesticides. Plant extracts break down readily without changing the pH of the soil, and because they include a variety of substances, it is difficult for diseases to develop resistance (Basim *et al*., 2012). Previous studies have shown that the aqueous extract of Rhus coriaria had antifungal and antibacterial properties in vitro (Rashid *et al*., 2023). Plant extracts are often volatile, difficult to handle, store, and costly to use for pest control purposes.

The hypothesis of this research aims to identify the active chemical compounds in sumac seed extract and evaluate their effectiveness in inhibiting fungi that cause plant diseases. By doing so, the research seeks to provide alternative biological methods for farmers and reduce reliance on harmful chemical pesticides.

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Materials and Methods

Preparation of plant extract: Twenty grams of the dry weight of sumac seeds were ground using a manual grinder after being disinfected with a 1% sodium hypochlorite solution and dried using filter paper, then baked at 50°C in an electric oven (Fig. 1). Before being utilized to make the water extract, the resultant powder was stored in sterile glass jars and put in a 500 ml glass beaker with 200 ml of distilled water. After 30 minutes of mixing the plant material using an electric mixer on a hotplate, the mixture was allowed to sit for another 30 minutes. After separating the larger particles with filter paper, the filtrate was moved to the centrifuge. The fine particles were sedimented with a Hera-type centralizer set to 3000 rpm for 10 minutes in order to produce a fine extract of the plant (Gupta *et al*., 2012; Odey *et al*., 2012).

Fig. 1. Sumac seeds and ground seed powder used to prepare water extract

Preparing the culture medium potato dextrose agar PDA: In order to make the potato medium, one liter of water was mixed with 400 g potatoes and boiled. Following that, 15.5 g agar and 20 g glucose were also added. Then, they were sterilized within the autoclave at 121°C as well as 15 pounds/inch2 for 40 minutes. Following sterilization, they poured them into Petri dishes (Pradeep *et al*., 2013; Ravimannan *et al*., 2014).

The fungi used in the experiment*:* The fungal isolates (F5) of Aspergillus sp., Pythium sp., and Fusarium oxysporum were obtained from the Plant Protection Department of University of Kufa and cultured on Potato Dextrose Agar (PDA) medium in an incubator at 25°C. This isolate is distinguished by the white mycelium with branched edges on the upper surface of the dish, and by the presence of a light cream coloration (Crozier, 2023). For this experiment, 5 mm discs from five-day-old colonies were used. A single disc of each fungus was placed in the center of a Petri dish filled with potato dextrose medium and a corresponding amount of each of the plant extracts studied, which actually provided the required concentration. After one week of incubation at 25°C, we measured colony length using the diagnostic methods used in the experiment (Alexopoulos *et al*., 1996; Singh *et al*., 2021). The antifungal activity of the extracts was assessed in Petri dishes by diffusion methods.

The following formula was used to calculate the relative growth inhibition of treatments compared to negative Control:

PIRG (%) = [Radial growth of control (mm) - Radial growth of treatment (mm)/Radial growth of control (mm)] ×100.

Field crops encounter numerous challenges that substantially decrease their production and quality, including pathogens that infect them at all growth stages and target various parts, resulting in adverse affects yield and quality, resulting to economic losses, particularly under favorable conditions, such as seed rot and the mortality of wheat seedlings caused by fungi. *Pythium* spp., *Rhizoctonia solani*, *Fusarium* spp. (Martin *et al*., 2015; Zhang *et al*., 2011).

Methodology of Gas Chromatography and Mass Spectrometry

Gas Chromatography–Mass Spectrometry (GC-MS) is a multifaceted analytical technique employed to identify several substances in a test sample through the integration of mass spectrometry and gas chromatography. GC-MS is utilized for drug detection, grain analysis, environmental assessment, explosives inquiry, unknown sample identification, and the separation and characterization of natural compounds and extracts (Leonil, 2000). Therefore, Figure 3 illustrates the chemical components found in sumac extract that are beneficial against fungus.

Assessing the Plant Extract's Inhibitory Potential

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A Completely Randomized Design (CRD) was used in the lab experiment to test four concentrations (12.5, 25, 50, and 100 ml/L) of sumac aqueous extract with three replicates to assess the efficacy against various fungi. Discs measuring 5 mm in diameter were removed from the pathogenic fungal isolates in Petri plates, and four concentrations (12.5, 25, 50, and 100) % of the plant extract were applied to the culture medium in addition to the control concentration to determine the inhibitory capacity against pathogenic fungus (20 cc of the culture media for each of the pathogenic fungi employed) in a 90 mm container. There were three replicates of each experiment, and the identical quantity of Petri plates was used. Following that, the dishes were incubated at 25°C. Following seven days, the growth rates of each harmful fungus were assessed after the control fungus had completed growth. Abbott's equation was then used to determine the extract's % efficacy in preventing fungal growth (Abbott, 1925). This is because, in addition to being comprehensive to use and devoid of chemicals and additives, the majority of current research demonstrates that the aqueous extract is superior to other solvents in terms of preventing the growth of mycoses (TAVGA, 2016).

These compounds work to form bonds between the hydroxyl and sulfhydryl groups of fungal cell proteins, which causes cellular proteins to precipitate and lose their function due to a change in their nature (Feeny, 1998).

The original mixture was formulated to combat harmful microorganisms in agriculture. Plant tissue was used to assess the developed formulation's ability to eliminate the pathogenic fungus B. cinerea, which is known to infect a range of crops, including tomato, melon, cucumber, zucchini, and grape plants. owing to its emergence as an indigenous crop, we adopted the evaluation the grapevine species. The generated formulation had to be stable, disperse uniformly throughout the plant, possesses emulsion characteristics, and not negatively impact the plant in any manner before it could be prepared for spray application. None of the substances in the formula (glycerol, water, an emulsifying mixture of mineral oil, and dimethyl sulfoxide) are toxic to the fungus at the doses used, either as a whole or in combination, when added without the leaf extract. Additionally, the preparation did not cause leaf damage or burning when applied to grape leaf tissue that was free of fungal infection, whether or not R. coriaria leaf extract was present, and its distribution was consistent. When the formulation with R. coriaria extract was sprayed on the fungus B. cinerea, fungal growth inhibition was observed compared to the control plate (Gili *et al*., 2023):

$$inhibition, \% = \frac{Fungal\ growth\ rate\ in\ comparison - Fungal\ growth\ rate\ by\ treatment}{Fungal\ growth\ rate\ in\ comparison} \times 100$$

Statistical Analysis: The laboratory experiment was conducted using a Completely Randomized Design (CRD) with three replicates to compare different fungi and four concentrations (12.5,25,50 and 100) ml/L of sumac water. A tool called Gene-STAT Version 21 was used to convert the recorded data into percentages in order to assess the antifungal extract. To find statistical significance a post-hoc test was applied.. Following a one-way analysis of variance of the data using GeneStat software (version 21), a significance level of $p \leq 0.05$ was established.

Results and Discussion

The outcomes demonstrated the presence of bioactive substances in the extract from sumac seeds, represented in terms of concentration and Retention Time (RT) using gas chromatography and mass spectrometry. (Figs. 2 and 3), demonstrating that the sumac seed extract contains ten bioactive phytochemical components that belong to specific classes of chemicals. Among the substances found in plants were a waxy white, saturated crystalline hydrocarbon solid, a teratogenic agent, alkane hydrocarbon 87, a long-chain alkane, a hydrocarbon used in the petrochemical industry, alkane hydrocarbon 91, heptocosan 91, 5,6-benzoquinoline, silica acid, and octasiloxane (Hexadecamthyl). Numerous chemical compounds identified by GC-MS analysis were present, as evidenced by the analytical results being comparable to those of ten chemical compounds.

The results of this investigation align with findings from various regions, highlighting the diverse chemical composition of sumac extracts. In Iran, the analysis of essential oils from R. coriaria (Abu-Reidah *et al*., 2014; Elagbar *et al*., 2020) collected from fourteen locations indicated at least five distinct bioactive compounds, including (E)-caryophyllene and nonanal-based. Similarly, researchers from Italy identified Monoterpenes and sesquiterpenes predominated, with β-caryophyllene and pinene isomers (Giovanelli *et al*., 2017). Gas Chromatography-Mass Spectrometry (GC-Mass) examination of the chemical components in sumac seed extract is shown in this chromatogram. The x-axis displays the identified compounds, including Octadecanoic acid, Silicic acid, Benzoquinoline, Heptacosane, Docosane, Eicosane, Tetratriacontane, Docosane, Ethyl phthalate, and Henicosane. The y-axis on the left (in blue) shows the Area Abundance (Area Ab's), indicating the relative quantity of each compound. The right y-axis (purple) represents the Quality of the peaks, while the green line illustrates the Retention Time (RT) in minutes for each compound (Arena *et al*., 2022). The red line indicates the Area Percentage (Area %), representing the proportion of each compound in the extract. The active compounds in the aqueous extract were identified using gas chromatography-mass spectrometry (GC MS). Based on the GC-MS results, 10 chemical compounds were reported from sumac seeds. The main components listed in the table were identified and tested for their antifungal activity. Among them, Ethyl phthalate and docosane were found to

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be among the most important antifungal component of sumac. The results obtained in the present study indicate that different extracts of R. coriaria exhibit a wide range of antifungal compounds that have the potential to be developed as a novel broad-spectrum antifungal herbal formulation for the control of tomato wilt disease (Tagva, 2016). Regarding antimicrobial activity against Staphylococcus aureus and Listeria monocytogenes was demonstrated by the results of the antimicrobial activity study of R. coriaria fruit samples. The fruits' enzyme inhibitory activity was 0.069 mg/ml (Öz *et al*., 2023). However, the eicosane found in this investigation exhibits inhibitory efficacy against foodborne pathogens that have been isolated from Cestrum nocturnum essential oils and organic extracts (Sharif *et al*., 2009). Eicosane is responsible for the antimicrobial action of Allium atroviolaceum flowers (Dehpour *et al*., 2011). The ethyl acetate extracts of compounds 1 and 2 were tested separately for their antibacterial and antifungal activities using the disk diffusion assay method (Rois *et al*., 1988). A kanamycin disk (30 µg/disc) and a nystatin disk (100 µg/disc) were used as positive antibacterial and antifungal controls, respectively. A blank disk saturated with the respective solvent was used as a negative control. The antibacterial activity of each, the Minimum Inhibitory Concentration (MIC) of the samples with antimicrobial activity, was determined using the serial dilution technique (Reiner., 1982). Heneicosane was found to exhibit excellent antimicrobial activity against S. pneumoniae 31±0.64 mm and A. fumigatus 29±0.86 mm, respectively, at concentrations of 10 µg/ml (Vanitha *et al*., 2020). While tetracontane, in particular, was associated with the chloroform extract of European thyme leaves, it was chosen as a source of antifungal agents for use against F. oxysporum, and could pave the way for finding new biological sources of agrochemicals (Hanaa, 2021). The rest of the discovered compounds like Heptacosane, 5,6-Benzoquinoline, Silicic acid, diethyl bis(trimethylsilyl) ester, Octasiloxane, hexadecamethyl also show antimicrobial and antifungal activity, which is consistent with previous reports (Sumaiya, 2023, Kumaresan,2015).

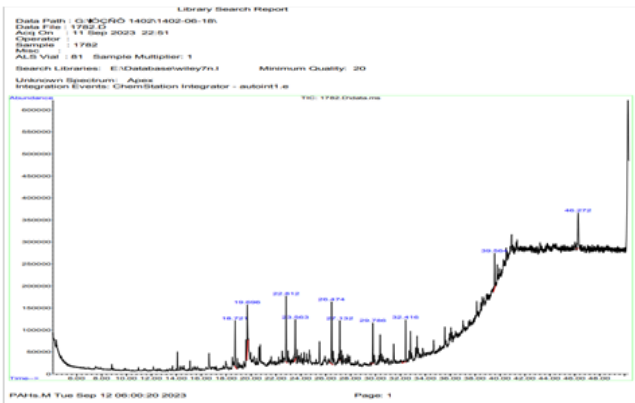

Fig. 2. GC-MS chromatogram of seeds aqueous extract Rhus coriaria. (Graphical illustration)

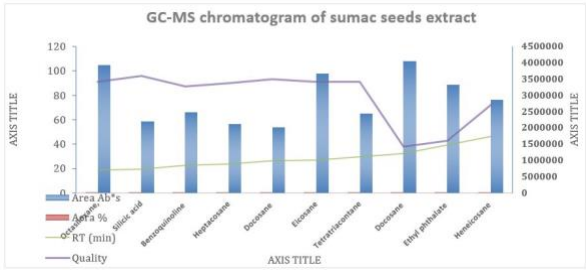

Fig. 3. GC–MS analysis chromatogram of sumac seeds extract

Each chemical constituent of sumac extract's quantity, peak area, and quality are also displayed in the diagram. Samples for the GC-MS chromatogram of the sumac seed aqueous extract were taken twice a week. 9.7 mL of 75% (v/v) ethanol and 0.1 mL of 30% (w/v) ammonium thiocyanate were added to 0.1 mL of this sample. A spectrophotometer was used to measure the absorbance of the reaction mixture with the generated red hue at 500 nm precisely three minutes after 0.1 mL of 0.02 M ferrous chloride in 3.5% hydrochloric acid was added (Kosar, 2007) (Figs. 2, 3) reveals several notable peaks, indicating the presence of different bioactive compounds. The peaks at retention times 16.876, 18.720, 22.918, 24.174, 26.236, 31.414, and 35.294 minutes represent substances such as docosane, tetratriacontane, heptacosane, eneicosane, and ethyl phthalate, among others. The highest peak, with a retention time of 46.272 minutes, suggests a significant concentration of this compound in the extract. Sumac's notable biological activities, health benefits, and industrial potential are attributed mainly to the predominant polyphenol compounds found in its plant materials (Khalil *et al*., 2021; Sakhr *et al.*, 2020). Docosane was present at 6.94%, and ethyl phthalate at 11.43%. Investigation of molecular docking interactions revealed that diisoctyl phthalate had the highest binding energy with fungal chitin synthase, which was determined at -7.90 kcal/mol. Thus, the present study demonstrates that Rhizobacterium B. subtilis KSAR2 strain may suppress the growth of R. solani and act as an effective biocontrol agent to protect plants from fungal infections. In addition, Ethyl phthalate can act as a natural biologically active fungicide (Abdulaziz *et al*., 2024).

Additionally, the essential oil contributes to sumac's biological activity and contains bioactive compounds that play a vital role in the plant's biological activity (Alsamri *et al*., 2021). As a result, Sumac's applications are rapidly expanding beyond its culinary uses to include pharmaceutical and nutraceutical products, food fortification, colorants, preservatives, and animal feed additives (Batiha *et al*., 2022; Olaiya *et al*., 2015).

This diversity and abundance of bioactive compounds highlight the potential of sumac seed extract for inhibiting plant pathogens, emphasizing its role in sustainable agriculture and green chemistry approaches.

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The following chemical components are revealed by the aquatic sumac extract's spectroscopic analysis results (Table 1) (Rashid *et al*., 2022).

How well Rhus coriaria works in controlling tomato anthracnose, caused by Colletotrichum acutatum, was tested in tomato plants and fruits. Interestingly, the aqueous extract of sumac fruits elicited significant antifungal activity against tomato anthracnose caused by Colletotrichum acutatum, suggesting that Rhus coriaria could be a cost-effective and environmentally friendly alternative to chemical fungicides in the management of tomato anthracnose disease (Fadia *et al*., 2017). The analysis results of sumac extract showed some new compounds compared to previous studies.

The compound Heneicosane emerged at minute 18.719 at location 2865279 with a peak area and a quality of 91 of 9.85. The compound ethyl phthalate emerged at minute 19.694 at location 3323983, with a peak area and a quality of 96 of 11.43. With a quality of 87 at 22.813 minutes, the compound Docosane emerged in the region 4038636, with a high area quality of 13.89., At 23.565 minutes, the chemical Tetratriacontane with a purity of 90 was seen in the region 2440286, Additionally, 8.39 is the peak area. Eicosane appeared at 26.476 minutes in area 3,673,420, with a quality score of 93 and a peak area of 14.20. The compound Docosane appeared at 27.13 minutes in area 2,017,985, with a peak area score of 91 and a relative area percentage of 6.94. Heptacosane, with a quality score of 91, appeared at 29.786 minutes in area 2,109,761, with a peak area of 10.30. The peak area of the compound 5,6-Benzoquinoline, which has a quality of 38, is 8.55 at minute 32.417 in the region 2486215. Diethyl bis(trimethylsilyl) ester appeared at 39.562 minutes in area 2,202,909, with a quality score of 43 and a peak area of 7.58 Octasiloxane, hexadecamethyl, appeared at 46.27 minutes in area 3,920,054, with a quality score of 72 and a peak area of 3.80. This compound was also detected in spectroscopic analysis. These findings are consistent with previous GC-MS studies identifying essential oil compounds in sumac seeds. The findings showed that the main compounds were Z, E-2,13-octadecadien, caryophyllene oxide, 2,4-decadienal, E-caryophyllene, and nonanoic acid (Shahrivari *et al*., 2024).

Table 1: Results of the GC-MS chromatogram for the spectral analysis of Rhus coriaria seed aqueous extract

No	Rate Time (min)	Peak Area (Ab*s)	Peak Area%	Name of Chemical components	Quality	CAS Number
1	18.719	2865279	9.85	Heneicosane	91	000629-94-7
2	19.694	3323983	11.43	Ethyl phthalate	96	000084-66-2
3	22.813	4038636	13.89	Docosane	87	000629-97-0
4	23.565	2440286	8.39	Tetratriacontane	90	014167-59-0
5	26.476	3673420	14.20	Eicosane	93	000112-95-8
6	27.13	2017985	6.94	Docosane	91	000629-97-0
7	29.786	2109761	10.30	Heptacosane	91	000593-49-7
8	32.417	2486215	8.55	5,6-Benzoquinoline	38	000085-02-9
9	39.562	2202909	7.58	Silicic acid, diethyl bis(trimethylsilyl) ester	43	003555-45-1
10	46.27	3920054	3.80	Octasiloxane, hexadecamethyl	72	019095-24-0

Table 2: Impact of sumac aqueous extract on plant pathogenic fungal colonies' medium diameter growth rate (%) in comparison to the control

Fungal pathogen	Concentrations of aqueous extracts (ml/L)				
	Control	12.5%	25%	50%	100%
F.oxysporum	67.78	42.45	26.76	24.21	22.33
Pythium sp	71.03	46.15	41.39	38.38	27.11
Aspergillus sp.	72.25	52.55	47.69	42.24	28.56
The average diameter and inhibition fungal colonies	70.34	47.05	38.53	34.61	25.99
LSD $_{0.05\%}$	Fungi = 1.002	Concentrations = 1.293		Interference = 2.240	

Table 2 shows that all aqueous extract concentrations inhibited fungal growth compared to the control. The average colony diameters were 25.99, 34.61, 38.53, and 47.05 mm for doses of 12.5, 25, 50, and 100 mL/L of Rhus coriaria aqueous extract, respectively. The control showed the largest colony diameter. We compared the applied concentrations and found that the extract's 100 ml/l concentration had the most potent inhibitory effect on the three fungi (Aspergillus sp., Pythium aphanidermatum, and Fusarium oxysporum).

The average colony diameters for the fungi were 22.33, 27.11, and 28.56 mm. These differences are attributed to the activity of bioactive compounds, while some volatile components may influence fungal growth (Christaki *et al*., 2012; Elgayyar *et al*., 2001).

The aqueous extract significantly inhibited fungal proliferation, with inhibition percentages of 25.99, 34.61, 38.53, and 47.05% corresponding to concentrations of 12.5, 25, 50, and 100 mL/L relative to the control (Fig. 4, Table 3). Among the tested concentrations, 100 mL/L of

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the extract exhibited the strongest inhibition against *Aspergillus sp.*, *Pythium aphanidermatum*, and *Fusarium oxysporum*. The corresponding average inhibition percentages were 69.17%, 75.62%, and 78.06%, respectively. The yellow coloration of Aspergillus sp. at 100% concentration indicates a substantial reduction in growth compared with Table 2 and other fungal species. The susceptibility of the pathogenic fungi to the aqueous plant extract varied, as shown by comparing the average percentage of fungal inhibition. Aspergillus sp. fungus was the most inhibited by the extract, followed by Pythium aphanidermatum and Fusarium oxysporum. The diffusion method was employed to assess the inhibitory activity of sumac seed extract against various fungi at different concentrations. The extract exhibited varying inhibitory capabilities against the studied fungal species, with Aspergillus sp. demonstrating more sensitivity than both Pythium aphanidermatum and Fusarium oxysporum. Furthermore, increasing the extract concentration enhanced inhibitory effects on all tested fungi (Kossah *et al*., 2013). The extract and seed coat showed strong antioxidant activity in the DPPH assay, with an IC50 of 0.02 mg/mL, among the highest reported for plants (Onkar, 2011). Additionally, sumac extract demonstrated antioxidant and free radical scavenging activities utilizing ferric thiocyanate and DPPH free radical scavenging assays. Sumac is thought to be a strong natural antioxidant (Hekimi *et al*., 2011). The primary constituents of Rhus coriaria (Shabbir, 2012) and its physiologically active chemicals (Doğan & Çelik (2016)) have been the subject of numerous investigations. Furthermore, a number of research have assessed its antibacterial (Raodah *et al*., 2014), antifungal (Ertürk, 2010), and antioxidant properties in order to assess its possible therapeutic impact (Ferk *et al*., 2007; Raodah *et al*., 2014; Ertürk, 2010).

Numerous studies have demonstrated that sumac exhibits superior antibacterial activity than that of antibiotics (Digrac *et al*., 2001). Another crucial aspect of homeopathic medicine is its antifungal properties. In one study, novel xanthones that were all efficient against fungal infections were discovered by analyzing extracts of sumac coriaria. Methanol (at concentrations of 1, 5, 10, and 20 mg/ml), corynaphthyl ether, coryraeroic acid, and coryraethracenyl ester (all at doses of 25, 50, 100, and 200 µg/ml) were used to extract various samples. For the testing, petri plates with Asbergillus flavus, Candida albicans, and Penicillium citrinum were utilized. The average inhibition zone that the extract produced in comparison to the control (fluconazole) served as the basis for the results. The corriaria thrasinyl ester extract was the next most inhibited zone, after the methanolic extract (Singh, 2011).

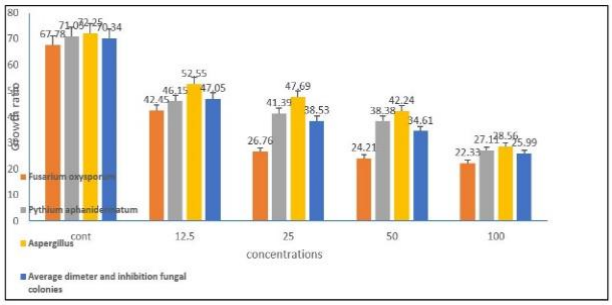

Fig. 4. Impact of sumac water extract on the development rate (%) of plant pathogenic fungal colonies' medium diameter

Table 3: Effect of Sumac Aqueous Extract at Various Concentrations (0, 12.5, 25, 50, 100 ml/L) on the Inhibition of Fungal Growth

Fungi	Concentrations of aqueous extracts (ml/L)				
	Control	12.5%	25%	50%	100%
Fusarium oxysporum	84.76	50.19	61.23	63.33	69.17
Pythium aphanidermatum	94.25	51.90	67.15	70.13	75.62
Aspergillus	97.58	57.43	69.01	74.13	78.07
The average diameter and inhibition fungal colonies	92.19	53.17	65.78	69.49	74.28
LSD $_{0.05\%}$	Fungi = 0.618	Concentrations = 0.798		Interference = 1.383	

Rhus coriaria fruits' antibacterial and antifungal effects on various bacterial hyphae and yeast were examined in a different investigation by Jiangnan University in China. Aspergillus niger and Candida albicans were the fungi under investigation. After 48 hours of incubation at 27 °C, their suspensions were adjusted to 107 cells/ml, and the zone of inhibition was measured. Their findings indicated that Rhus coriaria had a significant effect on both bacteria and fungi, with mean MIC values <0.25–0.5 µg/ml. Compared to nystatin, the antifungal activity of Rhus coriaria extract was significantly stronger (Ertürk., 2010). Pichia pastoris, Kluyveromyces lactis, and Saccharomyces cerevisiae were the subjects of additional antifungal research using Rhus coriaria extracts (Kossah *et al*., 2013). It was discovered that the fungal strains' minimal growth inhibitory limit ranged from 5200 to 7000 µg/ml (Ertürk, 2010).

This effect is attributed to the extract's bioactive compounds and trace amounts of water-soluble constituents from the essential oil. Active chemicals

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found in trace amounts of essential oil have an impact on fungal development (Rashid *et al*., 2023). Previous work on sumac extract indicated substantial antimicrobial activities for Gram-positive and Gram-negative bacteria (Mahdavi *et al*., 2018). Another study confirmed that the aqueous extract of sumac was effective against all tested organisms (Nasar-Abbas and Halkman, 2004). The maximum inhibition rate was obtained in the Sumac extracted oil of Xasto Zhere area against *S. aureus* compared with penicillin, amoxicillin, and enrofloxacin antibiotics (Shahrivari *et al*., 2024).

The percentage of fungal growth suppression (69.49, 65.78, and 53.15) in Figure 5 was significantly impacted by the crude sumac water extract in comparison to the control group at each concentration of aqueous extract (ml/L). The concentration of 100 ml/L was found to be the most effective when we examined the concentrations because it produced the maximum percentage of inhibition for the three fungus, Fusarium oxysporum, Pythium sp., and Aspergillus, was observed. Average inhibition percentages were 69.17, 75.62, and 78.07, respectively. Comparing the mean percentage of fungal inhibition, Since the extract had the highest percentage of inhibition for Fusarium oxysporum and Pythium aphanidermatum, we noticed that the susceptibility of pathogenic fungus to crude sumac extract differed; Then there's *Aspergillus*, due to the active compounds in the extract, which contain water-soluble active compounds. Active chemicals that impact fungal development are present in trace amounts of the essential oil. Previous studies have confirmed this. This is consistent with (TAVGA., 2016, Tuğba., 2022).

The maximum concentration (100 ml/l) of Sumac extract gave the most significant inhibitory effect on pathogenic fungi, particularly Aspergillus species, which exhibited the highest inhibition rate (Fig. 6). This indicates that the efficacy of sumac extract as a biopesticide increases with concentration, emphasizing its potential role in integrated pest management strategies. Sumac's hydrophilic extract exhibited potent antibacterial activity against a range of microorganisms, including S. aureus, P. aeruginosa, and others, and it might be crucial in hastening the healing process of wounds (Gabr & Alghadir., 2019). The ethanolic extract obtained from Sumac was diagnosed against Gram-positive and Gram-negative bacteria such as S. aureus, S. enteric, B. cereus, and E. coli. In this bacteria investigation, the extract caused E. coli to become resistant, while intense antimicrobial activity against all others was observed (Mahdavi *et al*., 2018). In farming, some plant-based extracts such as Phenols, sesquiterpenes, triterpenoids, and coumarins terpene hydrocarbons have lethal abilities on some crop pathogens (Abbey *et al*., 2019; Brown *et al*., 2019; Gikas *et al*., 2022; Sheir *et al*., 2015).

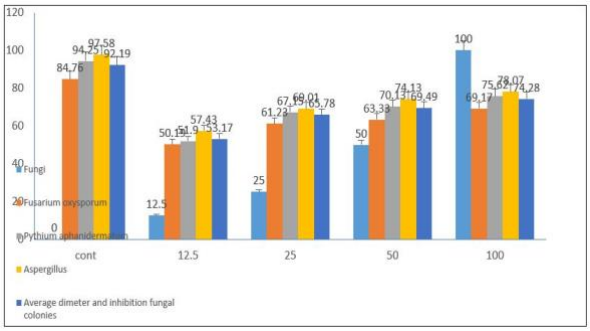

Fig. 5. Aspergillus sp., Pythium sp., and F. oxysporum inhibition ratios at different doses (12.5, 25, 50, and -100) % of sumac seed aqueous extract

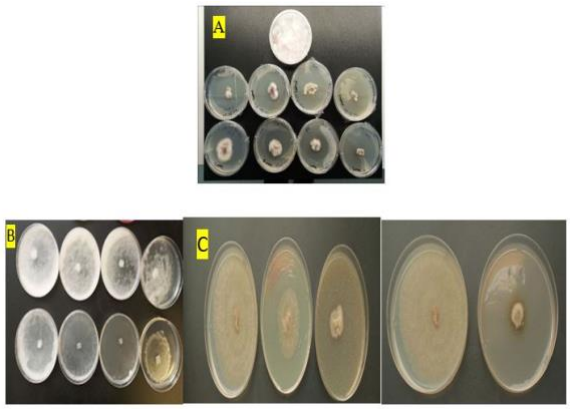

Fig. 6. Shows the growth rate of the fungi used in the experiment on Petri dishes according to the approved concentrations

Given synthetic fungicides' environmental and health impacts, stricter government regulations are expected (Wightwick *et al*., 2010), potentially increasing demand for plant-based alternatives. Plant extracts, which are effective, biodegradable, and less harmful, align well with sustainable agricultural policies (Mir *et al*., 2023). Relying on synthetic fungicides is not viable, especially in developing countries. Utilizing local resources and increasing bio-fungicide production should become standard practice. Additionally, the approval policies for the commercialization of biofungicides need to be regulated to support this transition (Cenobio-Galindo *et al*., 2024). Overall, the chemical diversity and bioactive potential of *Rhus coriaria* extracts, as demonstrated by studies from Iran, Turkey, Iraq, Jordan, and Italy, underscore the importance of this plant in developing natural antifungal treatments. Figure 6 shows the growth

rate of the fungi used in the experiment on Petri dishes according to the approved concentrations.

Conclusion

This study examined how well the aqueous extract of sumac seeds (Rhus coriaria) suppresses the development of Aspergillus sp., Pythium aphanidermatum, and Fusarium oxysporum at four different doses (12.5, 25, 50, and 100%). At the maximum concentration (100%), Aspergillus sp. exhibited the lowest growth rate (26.0%) and the highest inhibition rate (78.1%). The extract's antifungal qualities are supported by the existence of bioactive chemicals including eneicosane, ethyl phthalate, docosane, and tetratriacontane, and heptacosane that were discovered by GC-MS analysis. These compounds contribute to antifungal activity, suggesting that sumac extract is a promising biofungicide. Sumac extract is a possible substitute for commercial chemical pesticides due to its effectiveness, affordability, and environmental friendliness. Its use could mitigate the harmful effects of synthetic fungicides on the environment and human health, promoting eco-friendly agricultural practices and organic crop protection.

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Author's Contributions

Mohammed H. Al-Mamoori: Conducted the practical work and contributed to writing.
Meisam Zargar: Contributed to translation and communication with the journal.
Elena N. Pakina: Contributed to title selection and oversight of practical work.
Fatih Dadaşoğlu: Contributed to statistical analysis.

Conflict of Interest

The authors declare no conflict of interest.

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