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In vitro Antioxidant and Antimicrobial Pharmacological Investigations of Rhus coriaria L. (Sumac): A Review

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Abstract

The family Anacariaceae, which includes the species Rhus coriaria L., is a widely recognized spice often known as Sumac. It is classified within the Rhus genus and boasts a diverse range of over 250 species. Sumac is an abundant and naturally occurring botanical resource that possesses a diverse array of bioactive chemicals, hence rendering it highly versatile in terms of its potential therapeutics. The literatures indicate that it comprises many metabolites, such as hydrolysable tannins, minerals, and conjugated phenolic acids. Sumac has significant antioxidant activities attributed to the presence of phenolic components, specifically gallic acid and its derivatives. Sumac is commonly employed in the culinary sector as a spice and a fragrance enhancer for a diverse range of culinary dishes. This specific botanical specimen has been traditionally utilized in the field of medicine for the therapeutic management of many conditions, including weight loss, skin conditions, hair health, burns, headaches, hypertension, cancer, stroke, diabetes, dermatitis, stomach disorders, bowel complaints, and diuretic effects. Numerous in vitro investigations have been undertaken. This review encompasses a compilation of 71 scientific papers focused on Rhus coriaria, which collectively assert noteworthy in vitro antioxidant and antimicrobial properties. Based on the presence of phytoconstituents with therapeutic properties, this review aims to provide evidence for the reported in vitro findings in order to support their clinical usage.
Keywords: **Antioxidant, Antimicrobial, Ethnopharmacology, Phytoconstituents, Sumac**.

Introduction

The Anacardiaceae family includes the shrub or small tree Rhus coriaria L. (R. coriaria) [(1)]. The taxonomic classification of Rhus is frequently recognised in scientific literature as Sumac [(2)]. The etymology of the term "Sumac" can be traced back to its Arabic and Syriac origins, specifically the word "Summāq," which conveys the meaning of "dark red" [(3)]. The word Sumaga is the source of the name "Sumac" [(4)]. There are more than 250 distinct species of Sumac [(5)]. Iraq is home to the farmed or erratically growing Rhus coriaria L. species, which occurs adjacent to the villages in the north of the country [(6)]. The indigenous distribution of the genus includes the North Africa, Mediterranean region, the Caucasus, Afghanistan, Iran and Central Asia. The shrub in question is widely distributed throughout the Kurdistan region, primarily in the lower forest zone. The indigenous distribution of the genus includes the North Africa, Mediterranean region, the Caucasus, Afghanistan, Iran and Central Asia. It may be commonly observed in various areas such as the Sinjar mountain tract, as well as along mountain slopes in Duhok, Erbil, and Sulaimani. Its occurrence spans an elevation range of 530 to 1300 meters above sea level [(7)]. It is a perennial evergreen shrub or tree that can grow to be between 0.5 and 3 meters tall. It prefers to grow in calcareous, dry soil. The inflorescences, which resemble panicles, are made up of numerous tiny flowers with green-white petals that appear as the 3-5 mm-diameter dark crimson fruits ripen. The leaves have 9 to 15 broad, elliptic, lanceolate, and strongly serrated leaflets "Figure. 1" [(8)].

The reddish-brown, one- seeded fruits of the Sumach plant are used as a sour drink and as a seasoning in Middle Eastern cuisine [(9)]. Plants are significant sources of biochemical components in numerous agrochemicals, cosmetics, food stocks, preservation techniques, veterinary procedures, and leather processing technologies, in addition to being used in the development of pharmaceuticals [(10)]. In Iraq, it is customary to season salads that usually accompany similar foods, as well as renowned rich dishes like kabab and grilled meat, with it [(3)].

.Numerous studies have provided evidence supporting the notion that tannins possess anti-carcinogenic effects.

According to reports, this plant has noteworthy features such as anticancer, anti-inflammatory, antioxidant, antifungal, antibacterial, hypoglycemic, digestive, antidiabetic, and anticholinergic activities. Additionally, it has been observed to possess the capability to inhibit the formation of breast cancer tumors (11-12). Sumac also serves as a traditional medicinal remedy. The plant has been historically employed in the traditional medical system for the management of several ailments such as diarrhea, dysentery, ulcer, hemorrhoids, hemorrhage, wound healing, leucorrhea, pain, hematemesis, poison, sore throat, diuresis, ophthalmic, conjunctivitis, diuresis, animal bites, and liver disease. Traditional healers have long endorsed the utilization of this particular botanical specimen due to its recognized antibacterial attributes, as well as its perceived potential as an abortifacient, gastric tonic, and facilitator of weight reduction. It has also been employed for many objectives such as dermatological treatment, hair maintenance, wound healing, soothing gastrointestinal issues, mitigating cephalalgia, and lowering body temperature. Significantly, it has been utilized in the management of hepatic conditions, urinary tract diseases, and gastric ulcers. Recent studies have postulated that the phytochemicals included in Sumac possess the capacity to inhibit the activities of the COVID-19 virus. The utilization of pulverized fruits has also been identified as a method to augment sweating and decrease levels of cholesterol (13-15).

The medicinal applications of Rhus coriaria can be mostly attributed to its diverse biological features, including its antioxidant and antibacterial effects. Although there is abundant information regarding the extensive historical utilization of Sumac and its diverse phytoconstituents, we have not come across any studies that specifically emphasize these findings within the scope of our knowledge. To further the investigation of this plant and its potential medicinal uses, the present work was undertaken to comprehensively analyses antioxidant and antimicrobial in vitro pharmacological aspects of Sumac.

Taxonomical classification (16, 17):

Kingdom: Plantae
Sub kingdom: Tracheobionta
Super division: Spermatophyta
Division: Magnoliophyta
Subclass: Rosidae
Order: Sapindales
Family: Anacardiaceae
Genus: Rhus
Species: Rhus coriaria Linn.

Vernacular names (6, 17):

Arabic: Timtima, Tamtam, Sumak, Sumac
Bengali: Sumok Kashm
English: Sumach, Sumak, Sumac Sicilian
Frence: Sumac
Germany: Sumach
Hindi: Tatrak, Tatri
Kurdi: Trsh
Persian: Samaka, Samak, Sumaq
Turky: Sumbaq
Urdu: Sumaq.

Sumac fruit

Sumac plant

Figure 1. Sumac plant and fruits from Akre region in Kurdisatan, Iraq.

Ethnopharmacology

The use of Sumac in traditional medicine has been seen for many treatments including of diarrhea, dysentery, sore throat toothaches gastritis, stomach cancer, arteriosclerosis, bowel disorders, ring worms and for the protection of antiquities "Table 1" (7, 9, 11, 18- 31).

Table 1. Traditional uses Rhus coriaria.

Plant part	Traditional use	References
Fruit	Hemorrhoids, gout.	(7)
	Anorexia, anti-pus, smallpox, weight loss, hair, burns, digestive tract, measles, headache, skin treatment, and trachea treatment.	(11)
	As spice and appetizer.	(18, 19)
	Diarrhea, dysentery, sore throat and toothaches.	(19)
	Gastritis, stomach cancer, arteriosclerosis and for the protection of antiquities.	(20)
	Bowel disorders, Ring worms.	(21)
	Styptic, sedative and coolant activities.	(22)
	Eye inflammation, cancer.	(23)
	Abortifacient, animal bites, poison.	(24)
	Hepatic diseases, urinary system disorders.	(25)
	Antiseptic, blood purifier, stomachic and tonic.	(26)
	Cleansing the alimentary tract.	(27)
	Hypertension, hematopoiesis, hemoptysis, leucorrhea, ocular, conjunctiva, cancer, stroke, diabetes, aconuresis, headaches, dermatitis, leucorrhea.	(28)
	Astringent property.	(29)
	Fever, dermatitis, relieve stomach diseases, bowl complaints, diuretic and antiseptic.	(30)
Seed	Diuretic, astringent, appetizer, hemoptysis, conjunctivitis, styptic, and tonic; prescribed to treat dysentery.	(30)
Bark	Viral eye infections, and as a powerful teeth-cleaning agent when infused.	(26)
Leave	As a black dye	(9)
	Mouth sores and skin cracking.	(31)

Reported phytoconstituents

More than 200 substances from Rhus coriaria have been reported, and the majority of them show physiological activity "Figure. 2" (32). These chemical components fall into several classes and has been tabulated in "Table 2" (2- 4, 28, 32- 37).

Table 2. Reported phytoconstituents of Rhus coriaria.

S. NO.	Categories	Bioactive constituents	References
1.	**Hydrolysable tannins**	Methyl gallate, gallic acid, digallic acid, ellagic acid, O-galloylnorbergenin, Trigallic acid, galloylhexose, and O-galloyl arbutin	(33)
2.	**Phenolic acids**	Protocatechuic acid, gallic acid, p-OH-benzoic acid, and Vanillic acid	(34)

Counited table 2 .

3.	**Conjugated phenolic acids**	Digalloyl-hexose malic acid, galloyl-hexose-malic acid, Myricetin- hexose malic acid, kaempferol hexose-malic acid, quercetin-hexose malic acid. Isorhamnetin hexose-malic acid), Digallic acid, galloyl coumarate.	(33)
	Anthocyanins	cyanidin, peonidin, pelargonidin, petunidin, and delphinidin glucosides and coumarates	(33-35)
	Flavonoids	Myrecetin, Caryophelline, Chrysanthemin, Rutin, Kampferol, Isoquercetin, Myrtillin, Catechin, epigallocatechin, amenthoflavone, hinokiflavone, agathisflavone, and sumaflavone.	(3, 28, 36)
4.	**Organic acids**	Malic acid, Citric acid, Palmitic acid, Tartaric acid, Linolenic acid, Linoleic acid, Oleic acid, Stearic acid, Myristic acid, Palmitoleic acid, and Fumaric acid.	(33-36)
5.	**Coumarins**	Umbelliferone.	(33)
6.	**Xanthones**	2,3-dihydroxy7-methyl xanthone, 2,3,6-trihydroxy-7-hydroxymethylene xanthone-1-carboxylic acid, 2-methoxy-4-hydroxy-7-methyl-3-O-β-D-glucopyranosyl xanthone-1,8-dicarboxylic acid, 2-hydroxy-7-hydroxymethylene xanthone-1,8-dicarboxylic acid 3-O-β-D-glucopyranosyl- (2’→3’’)-3’’-O-stigmast-5-ene.	(37)
7.	**Terpenoids**	Polyisoprenoids, farnesylacetate, D-limonene, tocopherol mannoside, farnesylacetate, cembrene, and β-caryophillene.	(28)
	Steroids	B-sitosterol.	(32)
8.	**Essential oils**	α-Pinene, Cineole, Cembrene, Camphene, β-Pinene, Myrcene, β-Phellandrene, α-Terpinene, α-Copaene, Limonene, Terpinolene, Linalool, p-Cymene, Linalyl-acetate, Carvacrol, 2-Octanone, α-Humulene, Germacrene-D, β-Caryophyllene, and δ-Cadinene	(4)
9.	**Butein**	Chalconoid derivative.	(2, 32)
10.	**Minerals**	Potassium, calcium, magnesium, sulfur, cadmium, phosphor, lead, titanium, vanadium, copper, silicon, barium, chromium, lithium, brome, aluminum, chloride, manganese, iron, sodium, zinc, strontium, and nitrogen.	(28)
11.	**Vitamins**	Thiamin (B1), Riboflavin (B2), Pyridoxine (B6), Cyanocobalamin (B12), Nicotinamide (PP) Biotin (H), Ascorbic acid (C).	(36)

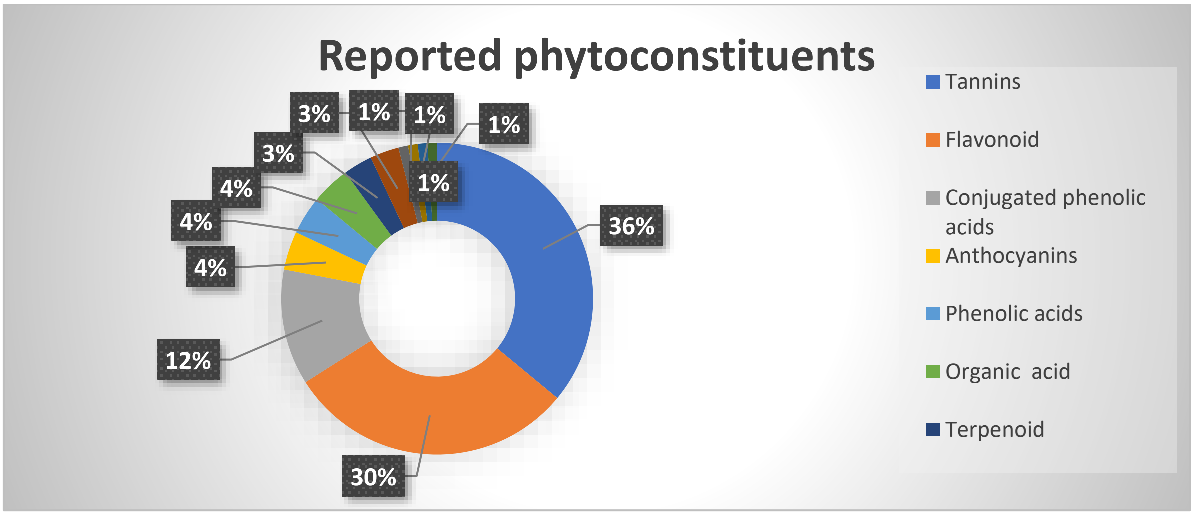

Figure 2. Reported phytoconstituents of Sumac [32].

Pharmacological activity

The pharmacological properties of Sumac have been extensively investigated through in vitro studies. In this review, we are examining a total of twenty-seven antioxidant activities and forty-four antimicrobial activities.

Antioxidant activity

The antioxidant properties of Sumac have been thoroughly investigated in a total of 27 studies, employing various assays such as 2,2-diphenylpicrylhydrazyl (DPPH), 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS), ferric reducing antioxidant power (FRAP), CUPric Reducing Antioxidant Capacity (CUPRAC), Dimethyl- p -phenylenediamine dihydrochloride (DMPD), Trolox equivalent antioxidant capacity (TEAC), Oxygen Radical Absorbance Capacity (ORAC), and Hydrogen peroxide assay (H_2O_2). Table 3 provides a comprehensive summary of the in vitro investigations conducted to assess the antioxidant characteristics of Sumac, encompassing various botanical constituents, extracts, methodology applied, and associated results. The "Table 3" displays the primary findings obtained from the previously stated inquiries [39-64].

Alawsy et al. (2020) reported on the antioxidant activity of tannin. The study's results indicated that the extract exhibited significant radical scavenging capabilities, as demonstrated by an EC_{50} value of 9 mg/ml. Furthermore, the tannin extract demonstrated DPPH radical scavenging activity, which was assessed in relation to the reference drug BHT (EC_{50}= 4 mg/ml). It is noteworthy to notice that the radical scavenging activity of the pure tannin extract was seen to be higher when compared to the partially purified tannin component, as shown by an EC_{50} value of 14 mg/ml. This finding indicates that the tannin concentration found in Sumac seeds has a higher level of quality when compared to BHT [18].

Al-Muwaly et al., 2013 tested SSE's antioxidant properties using several methods. The study found that Sumac seed aqueous, ethanolic, and methanolic extracts contained considerable phenolic and flavonoid components. The study found that the three solvent-soluble extracts (SSEs) have antioxidant capabilities, with methanolic SSEs being more antioxidant than aqueous or ethanolic SSEs [39]. Hosseini et al., 2020 assessed three varieties of Sumac seeds oil extract (Karaj, Hurand, Kurdistan) antioxidant properties using DPPH and FRAP tests. Karaj Sumac oil extract has the highest value which was 13.18 and 9.85 μmol α-TE/L for DPPH and FRAP, respectively [40].

Table 3. Antioxidant activity.

S. NO.	Extract (Plant part)	Model system	Result	Reference
1.	Ethanolic extract (Seed)	- DPPH assay.	Ethanolic extract IC_{50}= 9 mg/ml compared to BHT IC_{50}= 2.5 mg/ml Vitamin C IC_{50} = 4 mg/ml.	(18)
2.	Aqueous, ethanolic and methanolic extracts (Seed)	- Total antioxidant capacity - Reducing Power activity - DPPH assay - Nitric oxide scavenging activity - Hydroxyl radical scavenging activity - Metal ion chelating activity.	Among the three extracts, the methanolic Sumac extract exhibited highest antioxidant activity due to its abundant phenolics & flavonoids.	(39)
3.	Karaj, Hurand, Kurdistan Sumac oil extracts (Seed)	- DPPH assay - FRAP assay	Karaj Sumac oil extract has the highest value which was 13.18 and 9.85 μmol α-TE/L for DPPH and FRAP, respectively	(40)

Continued table.

4.	Goat milk yogurt fortified with Rhus coriaria (RC) (Leaf)	- ABTS assay - FRAP assay	Antioxidant activity (mg TE/g yogurt) - Undigested: ABTS - 7.88 FRAP - 1.11 - Upon gastric digestion: ABTS - 53.97 FRAP - 4.08 - Upon intestinal digestion: ABTS - 86.12 FRAP - 6.69	(41)
5.	Rhus coriaria L. phytocomplex (RC-P) (Leaf)	- DPPH assay	- RC-P - IC_{50} = 16.01 µg/ml	(42)
6.	Chloroform and methanol extracts (Leaf)	- DPPH assay - FRAP assay - CUPRAC assay - ABTS assay	Methanolic extract exhibited higher activity DPPH IC_{50} = 0.002 mg/ml ABTS - 0.069 mMTE/mg FRAP - 0.155 mMFeSO4/mg CUPRAC - 5.81 mMTE/mg	(43)
7.	Water extract (Leaf)	- ABTS assay - FRAP assay.	Water extract - ABTS - 725.75 mg TE/g - FRAP - 41.27 mg TE/g	(44)
8.	Hydroalcoholic extract (Leaf)	- DPPH assay	At concentration 200 µg/ml, % DPPH inhibition= 60- 70%	(45)
9.	Ethanolic extract (Fruit)	- DPPH assay	Percentage of inhibition at 1000 ppm - Extract - 95.25% - BHT - 93.75%	(46)
10.	Methanolic extract (Fruit)	- Peroxide value	At concentration 0.5% - Extract - 469.64 meq/kg - BHA - 63.16 meq/kg	(47)
11.	Ethanolic extract (Fruit)	- H_2O_2- induced oxidative stress	The maximum antioxidant activity were found in the EtOAc fraction (IC_{50} 2.57 g/ml).	(48)
12.	Ethanolic extract (Fruit)	- DPPH assay - TBARS assay - Peroxide value	- DPPH - IC_{50} value = 29.89 µg/ml - TBARS - IC_{50} value = 0.360 mg/kg - Peroxide value = 21.47 %	(49)
13.	Water, acetone and ethanol extracts of Fresh Red, Iranian Brown, Turkish Sumac and Fresh Brown Sumac (Fruit)	- FRAP assay.	Ethanolic Iranian Brown Sumac showed better antioxidant activity with a FRAP value = 27576 mmol/L	(50)
14.	Water and ethanol extracts (Fruit)	- DPPH assay - DMPD assay - CUPRAC assay - FRAP assay	Water extract - DPPH EC_{50}= 36.4 µg/ ml - DMPD EC_{50}= 44.7 µg/ ml	(51)
15.	Methanolic extract (Fruit)	- Inhibition of lipid peroxide formation. - Inhibition of superoxide radicals - Hydroxyl radical scavenging.	- Lipid Peroxidation IC_{50} = 1200 µg /ml - Superoxide-scavenging IC_{50} = 282.92 µg /ml - Hydroxyl radical scavenging IC_{50} = 3850 µg /ml.	(52)

Continued table3.

16.	Powder (Fruit)	- DPPH assay.	3.98 mg Ascorbic acid equivalent /g DW	(53)
17.	Phenolic Sumac Extract	- DPPH assay - TEAC assay	- DPPH IC_{50} = 0.41 mg/ml - TEAC IC_{50} = 0.21 mg/ml	(54)
18.	Powder (Fruit)	- DPPH assay	Total antioxidant capacity - 73.37 to 77.00%	(55)
19.	ESRF / RCLE composite films, ESRF ESRF/RCLE1 ESRF/RCLE2 ESRF/RCLE3 ESRF/RCLE4 (Fruit)	- DPPH assay	Among the five, the ESRF/RCLE4 showed highest percentage inhibition = 65.44 %.	(56)
20.	Methanol extract (Fruits)	- Superoxide Radical Scavenging activity.	IC_{50} = 232 mg/ml	(57)
21.	Water, acetone, and ethanol extracts (Fruit)	- FRAP assay	Total antioxidant activity of fresh brown Sumac - Water extract - 14.1 mol/L - Acetone extract - 14.2 mol/L - Ethanol extract - 27.4 mol/L	(58)
22.	Aqueous extract (Ripeness of fruit)	- ORAC assay	226,661.42 µmol TE/100 g	(59)
23.	Hydroalcoholic extract (Fruit)	- DPPH assay - ABTS assay	Percentage of inhibition at concentration 4 mg/ ml - DPPH Sumac - 0.19% compared to standard BHT- 0.20% - ABTS: Sumac - 97.22% compared to standard BHT- 100%	(60)
24.	Ethanol extract (Fruit)	- DPPH assay - ABTS assay	Percentage of inhibition at conc. of 20% (FB_S_4) - DPPH - 93.47% - ABTS - 99.79%	(61)
25.	Aqueous extract (Fruit)	- DPPH assay - ABTS•+ assay.	Percentage of inhibition of Rhus CuNPs nanoparticles - DPPH - 64.04% - ABTS•+ - 55.12%	(62)
26.	Aqueous extract (Fruit)	- DPPH assay	IC_{50} = 391 µg/ml	(63)
27.	Water, methanol (70%), n-hexane and dichloromethane extracts (Fruit)	- DPPH assay	Percentage of inhibition at concentration 100 µg/ml - Methanol extract- 56.11%	(64)

Abbreviations: Inhibition concentration (IC), Trolox equivalents (TE), Butylated hydroxytoluene (BHT), Hydrogen peroxide (H2O2), Ethyl acetate (EtOAc), Eremurus spectabilis root fructans (ESRF), Rhus coriaria L. extract (RCLE), Faba bean films (FB), Faba bean films sumac content (FB_S).

Antimicrobial activity

A total of forty-four investigations have been undertaken to examine the antibacterial effects of Sumac extract against a wide array of highly pathogenic reference strains, including both Gram-positive and Gram-negative bacteria, as well as fungi.

An assessment has been conducted to determine the antifungal efficacy of Sumac extract against Candida albicans. The fungal species Colletotrichum acutatum, Aspergillus flavus, and Penicillium citrinum are the subject of discussion [76, 77, 83, 88].

The bacterial strains that were included in the study encompassed Staphylococcus aureus, Pseudomonas aeruginosa, Escherichia coli, and Proteus vulgaris, as well as various species of Shigella, Bacillus subtilis, Pseudomonas syringae, Ralstonia solanacearum, Streptococcus enterica, Streptococcus mutans, Listeria monocytogenes, Streptococcus sanguinis, S. sobrinus, Strep. salivarius, Enterococcus faecalis, Klebsiella pneumoniae, Bacillus megaterium, Bacillus thuringiensis, Citrobacter freundii, Hafnia alvei, Aspergillus niger, Mycobacterium bovis, Babesia bigemina, Babesia divergens, Babesia caballi, Theileria) equi, Acinetobacter baumannii, Proteus mirabilis, Serratia marcescens, Salmonella typhimurium, Brevibacillus brevis, Enterobacter aerogenes, Micrococcus luteus, Caenorhabditis tropicalis, Shigella flexneri, Staphylococcus epidermidis, Corynebacterium xerosis, Shigella dysenteriae, Streptococcus pyogenes, Yersinia enterocolitica, Pseudomonas fluorescens, Bacillus pumilus, Branhamella catarrhalis, Clostridium perfringens, Erwinia carotovora, Yersinia enterocolitica, Lactiplantibacillus plantarum, Lactobacillus fermentum, Lactobacillus coryniformis Subsp. Torquens, Lactobacilli animalis, Lactobacillus acidophilus, Lactobacillus sp., Bordetella bronchiseptica, Bacillus pumilus, Enterobacteriaceae, Helicobacter pylori, Saccharomyces cerevisiae, Pichia pastoris, and Kluyveromyces lactis [1, 10, 37, 46, 60, 61, 64–100].

The existing body of research has been extensively researched and collated data on the antibacterial properties of many Sumac extracts, the procedures performed, the strains tested, the notable findings, and the observed therapeutic effectiveness that are outlined in “Table 4”.

A range of techniques were employed to assess the antibacterial efficacy of different Sumac extracts, including water, methanolic, ethanolic, acetonic, essential oil, petroleum ether, dichloromethane, ethyl acetate, and aqueous extracts. The procedures employed in this study encompassed agar disc diffusion, agar well diffusion, macrobroth dilution tests, and PCR testing.

Table 4. Antimicrobial activity.

S. NO.	**Extract (Plant part)**	**Method**	**Tested strain**	**Result**	**Therapeutic effect**	**Reference**
1.	Methanolic extract (Fruit)	Micro broth dilution	S. aureus E. faecalis P. aeruginosa A. baumannii E. coli K. pneumoniae P. mirabilis S. marcescens	Among the eight strains, S. marcescens exhibited highest MIC_{90} = 2048 µg/ml.	Antibacterial	(1)
2.	Light petroleum ether, dichloromethane, ethyl acetate, and methanol extracts (Epicarp of fruit)	-Disc diffusion method - Dilution method -Time-kill curve	S. aureus E. coli	Antibacterial with zone of inhibition showed strong activity of ethyl acetate fraction against both - S. aureus – 18 mm - E. coli – 12 mm	Antibacterial	(10)

Continued table4.

3.	Ethanolic extract (Seed)	Well diffusion method	Aspergillus flavus Candida albicans Penicillium citrinum	Zone of inhibition chloroform/methanol (3:1) at concentration 200 µg/ml A. flavus – 13 mm C. albicans – 17 mm P. citrinum – 13 mm	Antifungal	(37)
4.	Ethanolic extract (Fruit)	Micro dilution method	E.coli S.enteric S.aureus B.cereus	Staphylococcus aureus and Salmonella enteric exhibited highest susceptibility with a MIC of less than 0.78%.	Antibacterial	(46)
5.	Hydroalcoholic extract (Fruit)	Micro dilution method	-Salmonella Typhimurium -Listeria monocytogenes	- S. typhimurium MIC= 2.5 mg/ml - L. monocytogenes MIC= 5 mg/ml	Antibacterial	(60)
6.	Ethanol extract (Fruit)	Agar diffusion method	S. aureus E. coli	Zone of inhibition S. aureus - 26.00 mm	Antibacterial	(61)
7.	water, methanol (70%), n-hexane and dichloromethane extracts (Fruit)	Microdilution method	E. coli P. aeruginosa S. aureus C. albicans	Dichloromethane extract MIC value - E. coli - 62.5 µg/ml - P. aeruginosa- 125 µg/ml - S. aureus- 500 µg/ml - C. albicans- >1000 µg/ml	Antibacterial and antifungal	(64)
8.	Aqueous extracts (Fruit)	Disc diffusion method	Staph. aureus Staph. aureus (MRSA) Strep. aureus P. aeruginosa E. coli P. vulgaris Shigella sp	Zone of inhibition at 5 mg/kg - Staph. Aureus - 19.8 mm - Staph. aureus (MRSA) - 19.7 mm - P. aeruginosa - 13.7 mm	Antibacterial	(65)
9.	Essential oil extract (Fruit)	- Agar disc diffusion - Agar well diffusion - Macrobroth dilution assay	E. coli P. aeruginosa S. aureus B. subtilis	Zone of inhibition at concentration 15 mg/ml - Agar disc diffusion P. aeruginosa - 18.4 mm - Agar well diffusion P. aeruginosa - 10.4 mm	Antibacterial	(66)

Continued table4.

10.	Methanolic extract (Fruit)	-Colorimetric assay -Optical profilometry assay	Streptococcus mutans	At a concentration of 6 mg/mL, the production of S. mutans biofilm was seen to reduce by 77%.	Antibacterial	(67)
11.	Methanol, acetone, alcohol and aqueous extracts (Fruit)	-Disc diffusion method - Dilution method	P. syringae R. solanacearum	Growth inhibition zone at concentration 100 µg/ml Aqueous extract - P. syringae - 26.5 mm compared to Chloramphenicol – 24 mm - R. solanacearum - 23.5 mm compared to Chloramphenicol – 20 mm	Antibacterial	(68)
12.	Water extract (Fruit)	Real time PCR assay	S. mutans	MBC = 6.125 mg/ml MIC = 1.56 mg/ml MBIC = 0.39 mg/ml	Antibacterial	(69)
13.	Water extract (Ground plant materials)	Plate count agar	L. monocytogenes	MIC = 9 mg/ml	Antibacterial	(70)
14.	Water extract (Fruit)	-Well plate method -Macro-dilution method	S. mutans S. sanguinis S. sobrinus S. salivarius E. faecalis	Among the five strains, the extract exhibited the highest zone of inhibition= 29.33 mm against S. sanguinis at concentration 100 mg/ml	Antibacterial	(71)
15.	Aqueous extract (Fruit)	-Mueller Hinton agar - Agar dilution technique	Staphylococcus aureus	Zone of inhibition = 20 mm at concentration 75%.	Antibacterial	(72)
16.	Water, ethanolic and methanolic extracts (Seed)	Well diffusion method	MRSA B. subtilis EHEC P. vulgaris P. aeruginosa K. pneumonia	Among the three extracts, ethanolic extract exhibited the highest zone of inhibition MRSA - 25 mm B. subtilis - 23 mm EHEC - 16 mm P. vulgaris - 16 mm P. aeruginosa - 15 mm K. pneumonia - 15 mm	Antibacterial	(73)

Continued table4.

17.	Water extract (Fruit)	Cup method	B. cereus B. megaterium B. subtilis B. thuringiensis L. monocytogenes S. aureus C. freundii E. coli H. alvei P. vulgaris S. enteritidis	Growth inhibition zones - Ripened \Sumac (non-neutralized) P. vulgaris - 18.5 mm - Unripen Sumac (non-neutralized) P. vulgaris - 18.2 mm - Ripened Sumac (neutralized) P. vulgaris - 14.2 mm	Antibacterial	(74)
18.	Aqueous extract (Fruit)	Agar - well diffusion method	E. coli S. aureus B. cereus P. aeruginosa	Zone of inhibition E. coli - 10 mm S. aureus - 8 mm B. cereus - 7 mm P. aeruginosa - 8 mm	Antibacterial	(75)
19.	Aqueous extract (Fruit)	Agar - well diffusion method	Candida albicans	Zone of inhibition = 11.3 mm at conc. 200 µg/ml	Antifungal	(76)
20.	Acetone, aqueous, methanol, and ethanol extracts (Epicarp of fruit)	Disc diffusion method	Colletotrichum acutatum	Percentage inhibition redial growth (PIRG) at concentration 100 µg/ml. - Aqueous extract - 92% - Acetone extract - 80% - Methanol extract - 70% - Ethanol extract - 60%	Antifungal	(77)
21.	Alcoholic extract (Leaf)	- Diffusion disc plates on agar - Agar dilution method	B. subtilis E. coli S. aureus P. aeruginosa C. albicans A. niger	Zone of inhibition E. coli - 9 mm P. aeruginosa - 15.33 mm	Antibacterial and Antifungal	(78)
22.	Acetonic extract (-)		B. bovis B. bigemina B. divergens B. caballi T. equi.	IC_{50} value (µg/ml) - B. bovis - 85.7 - B. bigemina - 55.7 - B. divergens - 90 - B. caballi - 85.7 - T. equi - 78	Antibacterial	(79)
23.	Ethanolic extract (Fruit/flower and leaf)	- Well-Disk diffusion test - Microdilution method	E. coli S. aureus B. subtilis K.pneumoniae	Bacterial inhibition -Fruit or flower crude extract - 40% -Leaf crude extract - 54% -Leaf fraction F14 (Rc2) - 99% - MIC values S. aureus - 2.1 mg/ml K.pneumoniae - 2.5 mg/ml	Antibacterial	(80)

Continued table4.

24.	Water extract (Fruit)	Microbial culture and inoculum	S. typhimurium	Populations of S. typhimurium on tomato at concentration 4% - Before treatment - 2.71 log cfu /tomato - After treatment with water extract - 0.65 log cfu /tomato	Antibacterial	(81)
25.	Methanolic extract (Leaf)	Agar disc diffusion method	L. monocytogenes S. aureus E. coli P. aeruginosa	Zone of inhibition - L. monocytogenes - 21 mm - S. aureus - 20 mm - E. coli - 9 mm - P. aeruginosa - 18 mm	Antibacterial	(82)
26.	Chloroform extract (Fruit)	Disc diffusion method	B. megaterium B. brevis B. subtilis B. cereus E. coli E. aerogenes P. aeruginosa S. aureus L. monocytogenes M. luteus C. albicans C. tropicalis	Zone of inhibition - P. aeruginosa – 45 mm (std Tobramycin – 12 mm) - S. aureus – 51 mm (std Tobramycin – 13 mm) - L. monocytogenes – 46 mm (std Tobramycin – 7 mm)	Antibacterial and Antifungal	(83)
27.	Ethanolic extract (Fruit)	Well and disc diffusion methods	B. cereus S. aureus E. coli P. vulgaris S. typhi S. Xexneri	Zone of inhibition - S. aureus – 30 mm (std Gentamycin – 19 mm) - S. Xexneri – 30 mm (std Gentamycin – 20 mm)	Antibacterial	(84)
28.	Ethanolic extract (Fruit)	Disc diffusion methods	S. epidermidis C. xerosis	Zone of inhibition - S. epidermidis - 25 mm (std Gentamycin – 28 mm) - C. xerosis - 23 mm (std Gentamycin – 26 mm)	Antibacterial	(85)
29.	(Fruit)	Disc diffusion methods	B.cereus E. coli K.pneumoniae P.vulgaris P.aeruginosa S.dysentariae S.aureus S.epidermidis S.pyogenes E.faecalis Y.enterocoltica	Zone of inhibition - B.cereus - 26mm - P.vulgaris - 25mm	Antibacterial	(86)

Continued table4.

30.	Methanolic extract (Fruit)	Agar diffusion-method	P.aeruginosa, P. fluorescens B. subtilis B. cereus B. pumilis	Zone of inhibition - B. subtilis - 19 mm - B. cereus - 17 mm - B. pumilis - 18 mm	Antibacterial	(87)
31.	Methanolic extract (Fruit)	Agar- well diffusion method	B. cereus E. coli S. aureus B. catarrhalis C. perfringens C. albicans	Zone of inhibition of B. catarrhalis - $CHCl_3$ fraction - 6 mm - n-butanol fraction - 10 mm - EtOAc fraction - ≥ 11 mm	Antibacterial and Antifungal	(88)
32.	Ethanolic and water extracts (-)	-	Erwinia carotovora	Zone of inhibition at concentration 50 mg/ml - Ethanolic extract - 2.5 mm - Water extract - 3.5 mm	Antibacterial	(89)
33.	Ethanolic and aqueous extracts (-)	-	E. coli P. aeruginosa	Adhesion diameter at the concentration 40 mg/ml - Ethanolic extarct E. coli – 20 mm P. aeruginosa - 18.5 mm - Water extract E. coli – 17 mm P. aeruginosa – 14 mm	Antibacterial	(89)
34.	Acetone, ethanol, methanol, acetone + water, ethanol + water, methanol + water, water extracts (-)	Disc diffusion method	S. aureus E. coli K. pneumoniae	Zone of inhibition - Ethanolic extract - 14 to 16 mm - Methanolic extract - 22 to 25 mm	Antibacterial	(90)
35.	Methanolic extract (Fruit)	Well plate agar	S. aureus E. coli Y. enterocolitica lactobacilli strains (plantarum C27, L. plantarum L. fermentum L. coryniformis subsp. torquens L. animalis L. acidophilus Lactobacillus sp	Sumac had antibacterial activity against all of the pathogens that were examined.	Antibacterial	(91)

Continued table4.

36.	Methanolic extract (Fruit)	Agar - well diffusion	E. coli P. aeruginosa P. fluorescens K. pneumoniae B. bronchiseptica S. marcescens S. aureus S. epidermidis M. luteus B. cereus B. pumilus.	Zone of inhibition (K. pneumonia, B. pumilus, B. cereus, B. bronchiseptica, S. aureus, S. epidermidis) - ≥ 15mm	Antibacterial	(92)
37.	Ethanolic extract (Seed)	Microdilution method	P. aeruginosa	Sumac extract MIC value = 1.563 * 10^3 ug/ml	Antibacterial	(93)
38.	Water extract (Fruit)	Plate count agar	Enterobacteriaceae	MBC value (log10 cfu/g) - Distel water extract - 3.9 - Water extract - 2.6	Antibacterial	(94)
39.	Hot water, methanol and ethanol extracts (Seed)	Well diffusion method	B. subtilis P. aeruginosa	Among the three extracts, the ethanolic extract had the highest value of zone inhibition for both strains - B. subtilis - 23 mm - P. aeruginosa - 16 mm	Antibacterial	(95)
40.	Ethanolic extract (Fruit)	Agar diffusion assay	B. cereus B. subtilis S. aureus L. monocytogenes E. coli S. typhimurium H. pylori S. cerevisiae P. pastoris K. lactis	Zone of inhibition at concentration 5 %, w/v extract - B. cereus - 20.5 mm - B. subtilis - 17 mm - S. aureus - 19.5 mm - L. monocytogenes - 18.5 mm - H. pylori - 15 mm	Antibacterial	(96)
41.	Water, ethanol, water-ethanol, ethanol macerated, acetone and ethylacetate extarcts (Fruit)	Blood-agar dishes	H. pylori	The lowest zone of bacterial growth among the six extracts showed - Ethanolic water - 1-10% - Ethanol macetrated - 1- 10%	Antibacterial	(97)
42.	Water extract (Fruit)	Mueller–Hinton agar	S. aureus	MIC value - Meticillin-susceptible S. aureus - 3.7 mg/ml - Intermediate meticillin-resistant S. aureus - 2.5 mg/ml - Meticillin-resistant S. aureus - 3 mg/ml	Antibacterial	(98)

Continued table4.

43.	Methanolic extract (Leaf)	-	S. aureus E. coli	Antibacterial activity against both organisms – (98–100)%	Antibacterial	(99)
44.	Water extract (-)	-Disc diffusion assay -Agar (cup/well) Diffusion Assay	E. coli S. aureus	At conc. 50 mg/ml - Disc diffusion technique E. coli - 9.66 mm S.aureus - 13.49 mm - Agar diffusion technique E. coli - 10.14 mm S.aureus - 15.53 mm	Antibacterial	(100)

*colony forming units (cfu).

Conclusion

It has been discovered that Rhus coriaria contains a number of chemicals that serve crucial functions in homoeopathic medicine. Sumac has a significant impact on the improvement of human health and the economy because they are used to prevent oxidation, treat bacterial and fungal diseases, and perform a variety of other functions. Numerous studies have been conducted to determine how Rhus coriaria's antioxidant and antibiotic properties could be utilized. The purpose of this review is to examine in detail the phytochemical and biological research conducted on Rhus coriaria to date. There is substantial evidence that the subject has curative properties. In addition, the phytochemical components of the subject are enumerated, demonstrating their importance from a medical standpoint. Due to its antibacterial and antioxidant properties, scientists have investigated whether Sumac could be utilized as a dietary supplement. Antibacterial, antifungal, and antioxidant properties, among others, make this chemical an excellent choice for use in the food industry. Sumac effectiveness as a food preservative and its status as a safe, naturally occurring food additive enhance its utility.

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Conflicts of Interest

The authors declare that there is no conflict of interest.

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