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Phytochemical and nutritional properties of sumac (*Rhus coriaria*): a potential ingredient for developing functional foods

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ABSTRACT

Sumac (*Rhus coriaria*) is a flowering plant that is widely consumed for its promoting health benefits and used in food preparations as a spice in the Mediterranean region. It is a high shrub or small tree with imparipinnate leaves, villus and red fruits with one-seeded drupe, and small greenish-white flowers. The nutraceutical and pharmaceutical potential of sumac makes it a remarkable functional food. In this review, the phytochemical and nutritional properties of sumac as an under valorized functional food have been discussed. Flavonoids, anthocyanins, phenolic acids, and organic acids have been reported as dominant phytochemicals in sumac, which are well known for their pharmacological properties that attract many consumers to commonly choose sumac in their diet as well as food preparations. The remarkable volatile compounds present in sumac give it a unique aroma that increases its acceptance by consumers and potential use in the food industry. Sumac has been evaluated for a broad range of nutritional and pharmacological activities such as antioxidant, antinociceptive, anti-inflammatory, anti-diabetic, hepatoprotective, cardioprotective, anticancer, anti-infertility, and neuroprotective potential. This review has also briefly outlined the safety concerns concerning the use of sumac in terms of toxicology and interactions.

1. Introduction

Today, humanity and especially most communities in developing countries depend on medicinal plants as a valuable heritage for their primary health care and substances. Functional foods (FFs) are those foods that may promote health benefits beyond their supply of essential nutrients. Owing to its basic nutritional and nutraceutical properties, a functional food can decrease the risk of the onset of many chronic diseases, and can contribute to health[1-2]. FFs can be considered as whole, fortified, enriched or enhanced foods that provide health benefits beyond the provision of essential nutrients (e.g., vitamins and minerals) when they are consumed at efficacious levels as part of a varied diet regularly[3]. *Rhus coriaria*, also called sumac, is a high shrub or small tree (1–3 m high) with

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imparipinnate leaves, villus, and red fruits with one-seeded drupe, and small greenish-white flowers organized in panicles[4-5]. Given its nutritional value and its phytochemical components (flavonoids, flavones, anthocyanins, tannins, organic acids, fibre, proteins, volatile oils, nitrites, and nitrates), it has been used both as a spice and gives a sour lemon taste to various foods such as vegetables, meat dishes and rice then as a medicinal herb. It contains natural pigments such as anthocyanins and is used as coloring agents in food industry[6-7]. Research efforts on sumac extracts to date indicate a promising potential of the species of this genus to provide bioproducts that have desirable biological activities: antifungal, anti-inflammatory, antimalarial, antimicrobial, antitumorigenic, antioxidant, antiviral, hypoglycaemic, anti-inflammatory, antimalarial, antimicrobial, antitumorigenic, antioxidant, and antiviral. In traditional medicine, this plant has been used in the treatment of many diseases such as cancer, stroke, diarrhoea, hypertension, dysentery, haematemesis, ophthalmia, stomach ache, diuresis, diabetes, atherosclerosis, measles, smallpox, aconuresis, teeth and gum ailments, headaches, animals bites, dermatitis and liver diseases[8]. Sumac may also have the potential for the prevention or treatment of atherosclerosis and its clinical manifestations. The target of this study was designed to evaluate sumac (*R. coriaria*) as an undervalorized functional food.

2. Methodology of data collection and analysis

The data published on *R. coriaria* between 1972 and 2022 was collected from different sources such as Google Scholar, Web of Science and Scopus. The keywords or information searched were sumac, *R. coriaria*, botanical characteristics, nutritional values, uses and economic values, bioactive compounds, biological activities, and safety. During the searching approches “AND” “OR” were also included.

3. Botanical description

R. coriaria, commonly known as sumac (Fig. 1), is a flowering shrub of the family Anacardiaceae of the order Sapinidae, with about 81 genera and more than 800 species. Sumac is widely distributed in subtropical and temperate regions around the world, especially in Africa, southeastern Anatolia, the Mediterranean and western Asia. The genus includes about 250 species worldwide[9].

3.1 Morphology

R. coriaria is a shrub and small tree that can grow up to 10 meters tall. The leaves are spirally arranged, mostly pinnate, and some species have trifoliate or simple leaves. The flowers are in dense panicles or spikes, 5–30 cm long, each flower is small, green, creamy white or red with five petals. Single-seeded fruit diameter (3.5–4.0 cm long, 2–2.5 cm wide), forming dense clusters of red drupes called sumac. The seeds are slightly hard, brown, in diameter (0.3–0.5 cm long, 0.2–0.3 cm wide), with a good spicy smell[8,10-11].

3.2 Ecology and cultivation

Sumac reproduces by seeds (spreading by birds and other animals through their droppings) and shoots from rhizomes, forming large colonies. The plant is wild and/or cultivated in temperate and tropical regions of the continent, capable of growing on riverbanks. *R. coriaria* has shallow penetrating roots to reduce soil drift and can be planted on poorly eroded soils. The type of sumac that is grown commercially in the Mediterranean and Middle Eastern red sumac, has been cultivated for centuries to produce quality material for tanning. It is also wild in areas from the Canary Islands to Mediterranean beaches to Afghanistan, as it is common in the Mediterranean and southeastern Turkish territories[11-12]. Most researchers interested in sumac say that *R. coriaria* grows in mountain environments.

4. Uses and economical aspects

Sumac is a plant belonging to the same family as pistachio and cashew trees. It is found in tropical temperate regions as well as in the Mediterranean basin in southern Europe and the countries of the Middle East. It is found in large numbers in the northern and southeastern regions of Turkey as well as in Lebanon[5].

Native to the Mediterranean basin and the Middle East, sumac has been known since ancient times for its therapeutic and nutritional virtues widely used in oriental cuisine, particularly for its lemony flavour as well as for its digestive and aperitif properties. Supplement capsules and essential oils are made from the different parts of sumac[13]. Since ancient times the Romans and Greeks used it to replace lemon and vinegar and for its ability to facilitate digestion as well as its febrifuge properties.

Processed and consumed in the form of oil, it is used in folk medicine for the treatment of certain diseases such as digestive and urinary disorders as well as chest pain[8]. Sumac also promotes sweating, fights fever and protects from the intestinal irritation. Infused, it also relieves skin infections. Often used as an astringent medicinal plant, it is also used to relieve sore throat because of its antiseptic properties[11]. According to Khalil et al.[1], Sumac can be used as an anti-cholesterol and anti-inflammatory. As a decoction, it is still used today a lot in Middle Eastern cuisine and to relieve gastric disorders. White sumac, a related species found in temperate regions of the United States, was used by Native Americans to treat haemorrhoids, inflammation, and mouth sores. It is also a good remedy for relieving rheumatism. Sumac also has strong hypoglycemic properties that reduce blood glucose levels and improve glucose tolerance in diabetic patients[14]. The vasodilatory properties of its leaves make it a protective agent of the cardiovascular system. It also has antioxidant properties for DNA protection. In addition, recent research conducted by Korkmaz[15] reports the potential of sumac extract in the treatment of COVID-19.

In gastronomy, the seeds are used as an aperitif like mustard, and they are tasted before the meal. Sumac fruits reduced to powder can be used in cooking as a spice. Sumac is one of the main spices found in spice blends popular in the Middle East[16]. As a spice, mixed with oregano, it enhances the flavour of dishes.

According to Sakhr and El Khatib[11], sumac also has strong economic potential. Indeed, 100 g of dried and ground sumac are sold for about 5 USD; 20 seeds cost approximately 2 USD and a young sumac plant is worth about 3 USD. This testifies to the real potential that sumac represents from an economic point of view. It would therefore be a potential source of wealth for planters, processors and all other actors in the value chain.

Although sumac has many advantages in the therapeutic, pharmaceutical, culinary as well as the economic benefits. However, it is important to take certain precautions when using it. Indeed, sumac and especially its leaves can have a very powerful toxic effect[13]. It is strongly recommended not to proceed with the harvesting and preparation of sumac without prior expert advice. In addition, consuming standardized preparations packaged in the recommended doses will achieve maximum benefits with limited health risks.

5. Nutritional properties

R. coriaria plants are known to be rich in tannins (condensed and hydrolyzable), phenolic acids, anthocyanins, gallic acid derivatives, flavonoid glycosides and organic acids[8]. The leaves, fruits, and seeds of *R. coriaria* are reported to contain many phytochemical components. These chemical constituents can be divided into different classes of hydrolyzable tannins, phenolic acids, conjugated phenolic acids, anthocyanins, flavonoids, organic acids, coumarins, xanthones, terpenoids, steroids, essential oils and other constituent groups[8,17]. These substances are of great interest to human health today because they reduce the risk of chronic disease. Several studies have shown that these substances have antioxidant, antibacterial, hypoglycemic, hypolipidemic, anti-ischemic, anti-mutagenic, DNA protection and anti-migration activities. Phytochemicals of fresh and dried sumac fruit (Fig. 1) have shown interesting value making all different parts of this plant a promising source of functional ingredients.

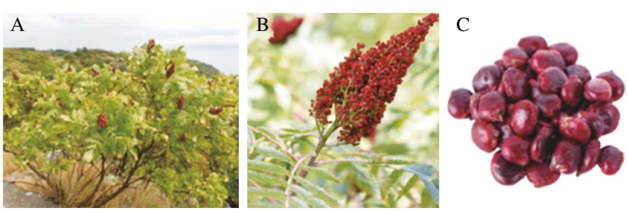

Fig. 1 (A) Sumac plant; (B) Sumac fruits; (C) Sumac seeds.

Studies showed that consuming sumac positively affects antioxidant status and cholesterol levels in rabbits, suggesting that the plant can reduce blood cholesterol levels in animals and humans[18-19]. The administration of the feed containing various doses of sumac (0.50%, 0.75%, 1.00% and 1.50%) to rabbits revealed to significantly decrease the cholesterol levels and increase the total antioxidant status and level of albumins[18]. Broiler chickens were fed with various diets containing 2.5 to 10 g of sumac powder per kilogram of diet and it resulted that the dietary supplementation of sumac reduced the blood total cholesterol, very low density lipoprotein and plasma fasting blood sugar levels, which are associated to the decrease of activity of HMG-CoA reductase and α-amylase activities[20]. *In vitro* and *in vivo* studies have shown that tannins have anticancer effects. Likewise, aqueous and aqueous methanolic extracts of *R. coriaria* leaves and fruits revealed the presence of gallotannins, which can lower blood urea nitrogen and blood pressure[21].

In addition, *R. coriaria* fruit has been found to contain various fatty acids, including azelaic, tetradecanoic, elaidic, stearic, eicosadienoic, arachidic, and tetracosanoic acids, as well as oil acid (omega 9), palmitic acid and linoleic acid. Omega 6 is the main fatty acid in sumac[22]. Minerals such as potassium, calcium, and magnesium have been found to predominate in sumac. Other minerals were also explored, namely sulphur, cadmium, phosphorus, lead, titanium, vanadium, copper, silicon, barium, chromium, lithium, bromine, aluminium, chloride, manganese, iron, sodium, zinc, strontium and nitrogen[23]. Interestingly, the fruits and seeds of *R. coriaria* are rich in antioxidants, vitamins A and estimated that sumac is 50 times more potent than vitamins C and E as antioxidants[24].

Table 1
Physico-chemical composition of sumac fruits (dried and fresh) and seed.

Chemical properties	Fresh fruit	Dried fruit	Seeds	References
Moisture (%)	10.60	2.30	3.10–7.50	
Total fat content (%)	7.40	18.74	17.18–19.64	
Crude protein (%)	2.60	4.69	5.66	
Crude fibre (%)	14.60	ND	27.50	
Carbohydrate (%)	ND	71.21	39.74	
Crude energy (kcal/100g)	147.80	ND	ND	
α-Tocopherol (mg/kg oil)	ND	ND	402.69	[71-74,77]
γ-Tocopherol (mg/kg oil)	ND	ND	45.63	
Ash (%)	1.80	2.93	2.26–4.22	
Water-soluble extract (%)	63.80	ND	ND	
Acidity	4.60	ND	2.01–7.84	
pH	3.70	3.02	2.66–3.90	

ND, not determined.

Glucose, fructose, xylose, and sucrose are the main carbohydrates found in sumac's different plant organs. Interestingly, sumac fruit is known to contain a dietic sugar source, namely xylitol[25-26]. The fruits skin and pulp constitute the principal sources of carbohydrates. Ozcan et al.[24] characterized glucose (0–0.75%), fructose (0–1.93%), sucrose (1.41%–5.85%), and xylose (8.53%–18.19%) in 15 genotype of sumac fruits (Table 2). The authors pointed out that xylose was the predominant carbohydrate in all the sumac genotypes. In another study published by Demchik et al.[25], sumac fruit was also found to contain a great amount of xylan (17.07%–27.90%), and glucan (11.27%–16.73%), low concentration of galactan (2.43%–4.13%) and arabinan (0.5%–0.9%). Fucose and mannose were also reported by the same authors. The significant amount of xylose in sumac makes it valuable for the production of xylitol, which is used in several food and industrial products[26].

Table 2
Ranges of carbohydrate content of mature and dry fruits of sumac.

Carbohydrates	Amount (%)	References
Glucose	0–0.75	
Fructose	0–1.93	
Xylose	8.53–18.19	
Sucrose	1.41–5.85	
Glucan	11.27–16.73	[24-25]
Galactan	2.43–4.13	
Arabinan	0.50–0.90	
Xylan	17.07–27.90	

6. Phytochemical composition

Phytochemical compounds also known as specialised metabolites are found in plants with varied chemical structures and concentrations. In this group of compounds, phenolics remain the largest class of compounds. The modern advanced analytical technique using GC-MS and LC-MS/MS has revealed that the different parts of sumac contain tremendous phytochemical compounds mainly a range

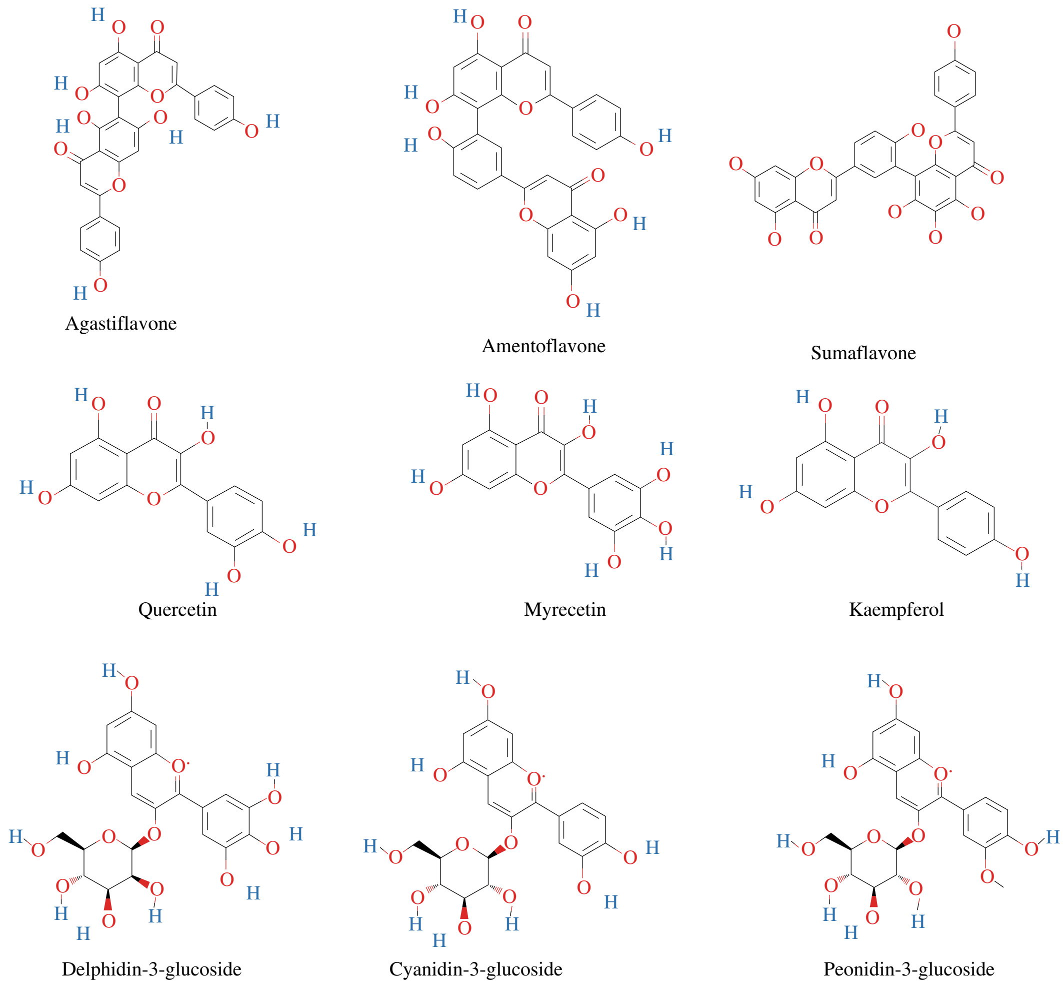

Fig. 2 Chemical structure of some flavonoids and anthocyanins compounds from sumac (PubChem).

of phenolics (flavonoids, phenolic acids), tannins, organic acids, volatiles and some polysaccharides. Table 3 shows some dominant phenolics, carbohydrates, organic acids and volatile compounds reported in sumac plant organs. Total phenolic contents in sumac fruits were 151.71 mg gallic acid equivalents (GAE)/g and 65.31 mg GAE/g on dry weight basis using methanolic and ethyl acetate extracts, respectively. Similar research investigated in Turkey using 15 genotypes of sumac fruits indicated that total phenolic contents ranged from 36.8 mg GAE/g to 58.46 mg GAE/g on dry weight basis[25]. Of all the phytochemicals, flavonoids were found to be qualitatively the dominant compounds in sumac. More than 200 phytochemical components using HPLC-DAD-ESI-MS/MS method have been tentatively identified in sumac fruits[27]. The phytochemical compounds in sumac remain to be fully elucidated as they were reported to have potential health benefits.

6.1 Flavonoids

An investigation of phenolic compounds in sumac using HPLC-MS technique in different countries by some researchers indicated several flavonoids including flavanones, flavonols, flavones flavanols, isoflavanones along with anthocyanins[11]. The concentration of these compounds greatly differs between sumac fruits, seeds, leaves, fruit ripening stages and also the growing region. Flavonoids quantitatively constitute the second most abundant compounds after hydrolysable tannins in sumac fruit. Fig. 1 shows the structure of some flavonoid compounds mostly identified in sumac plant organs. The total flavonoid content of different genotypes of sumac fruits was found in the ranges of 10.87–119.74 mg/kg[25]. The study carried out by Abu-reidah et al.[27] revealed 61 individual flavonoid components and derivatives in sumac plant organs. Interestingly, flavones and flavonols compounds were reported to be the dominant flavonoids in sumac leaves and fruits. An investigation reported quercetin, myricetin, and kaempferol as the main flavonols in the sumac leaves extracts, in which myricetin was found to be the prevailing compound[28]. Additionally, epicatechin, catechin, and rutin were identified and quantified as flavonols, and narirutin as flavanone compounds in sumac leaves extract. Zannou et al.[5] found a total flavonoid ranged from 4.08 to 17.57 mg ECE/g in the sumac extracts obtained with water, methanol and ethanol as well as deep eutectics solvents (choline chloride-lactic acid and choline chloride-acetic acid). Also, they found that catechin (66.95×10^{-6}–$1\ 266.19 \times 10^{-6}$) was the most abundant flavonoid in sumac compared to quercetin-3-glucoside (10.89×10^{-6}–136.92×10^{-6}). These compounds are now included as nutritious healthy food ingredients in the consumer's diet due to their valuable health benefits.

Table 3
Proximate composition of predominant phytochemicals in sumac organs and essential oils.

Sumac parts	Compounds	Amount	References
	Flavonoids (mg/g)		
Fruit and leaves	Quercetin	0.231–0.336	[5,27,30]
	Myricetin	0.316–1.082	
	Kaempferol	0.032–0.170	
	Epicatechin	0.035–0.193	
	Catechin	0.024–1.300	
	Quercetin-3-*O*-glucose	0.010–0.136	
	Rutin	28.42–111.03	
	Narirutin	10.86–93.99	
	Anthocyanins (mg/g)		
Fruit	Delphinidin-3-glucoside	2.8	[5,28]
	Cyanidin-3-glucoside	0.043–78.400	
	Cyanidin-3-rutinoside	0.012–0.057	
	Pelargonidin-3-glucoside	0.381–1.184	
	Cyanidin chloride	0.015–0.055	
	7-methyl-cyanidin-3-galactoside	529.2	
	7-methyl-cyanidin-3(2″galloyl)-galactoside	3.51	
	Phenolic acids (mg/g)		
Fruit and Leaves	Gallic acid	0.29–12.04	[5,30]
	Rosemarinic acid	0.011–0.217	
	Chlorogenic acid	0.005–1.160	
	Vallinic acid	0.007–0.022	
	Caffeic acid	0.001–0.100	
	p-Coumaric acid	0.002–0.410	
	Ferulic acid	0.001–0.034	
	Salicylic acid	1.07–5.97	
	Syringic acid	0.002–0.010	
	Organic acids (μg/g)		
Fruit	Malic acid	1 360.0–2 800.0	[24,41]
	Oxalic acid	1.30–2.90	
	L-Ascorbic acid	4.03–21.40	
	Citric acid	49.80–95.10	
	Fumaric acid	0.41–3.40	
	Tartaric acid	1.20–2.15	
	Volatiles (mg/g)		
Fruit and essential oils	*β*-Caryophyllene	40.2–137.9	[34-35,40]
	α-Pinene	2–260	
	E-caryophyllene	59–503	
	Cembrene	19–217	
	Camphor	3–125	
	n-Nonanal	18–233	
	(2*E*,4*E*) decadienal	24–165	
	Nonanoic acid	158	

6.2 Anthocyanins

The anthocyanins are natural pigments and constitute a class of flavonoid derivatives present mostly in the skin of sumac fruits. Sumac's different parts, mainly the fruits contain a significant reservoir of anthocyanins[27]. The total anthocyanins content of sumac fruit extracts using different solvents ranged from 39.73 to 171.96 mg cyanidin-3-glucoside equivalent/kg[29]. The red colour of sumac fruits has been associated with the presence of anthocyanins and it has been traditionally utilized to preserve and colour meats when sprinkled over the Kebab and grilled meats, in soup and salad. The recent identification of flavonoids in sumac fruits with a range order of content showed delphinidin-3-glucoside, cyanidin 3-(2-gallolyl) galactoside, cyanidin-3-glucoside, 7-methyl-cyanidin-3 (2 gallolyl) galactoside, 7-methyl-cyanidin-3-galactoside as the main anthocyanins[29]. The chemical structure of some anthocyanins mainly detected in sumac plant organs is shown in Fig. 1[27]. Other anthocyanins, namely peonidin-3-glucoside, petunidin-3-glucoside coumarate, delphinidin coumaroyl glucosides, delphinidin-3-glucoside coumarate, and cyanidin coumaroyl glucoside in sumac were also established[30]. Recently, Zannou et al.[5] reported that the extraction of anthocyanins from sumac is highly affected by the type of solvents. They determined that the total monomeric anthocyanin is in the range of 0.67 to 2.31 mg/g and pelargonidin-3-glucoside (395–1 198 mg/kg) was the most dominant compound extracted from sumac, followed by cyanidin-3-glucoside (40–115 mg/kg), cyanidin-3-rutinoside (12–59 mg/kg), and cyanidin chloride (12.5–58.0 mg/kg).

6.3 Phenolic acids

Hydroxycinnamic and hydroxybenzoic acids form the two classes of phenolic acids in the sumac plant. However, hydroxybenzoic acids are the major group of phenolic acids found in sumac. The total phenolic acid was quantified as 1 213.49 μg/g of sumac leaf extract[31]. A study reported four phenolic acids, including gallic acid, vanillic acid, *p*-benzoic acid, protocatechuic acid with various concentrations in different extracts of the sumac plant, in which gallic acid was found to be the prominent component in the sumac[30,32]. In another study performed by Perna et al.[30] on sumac, a total of 7 individual phenolic acids including gallic acid (924.36 μg/g), rosemarinic acid (217.02 μg/g), chlorogenic acid (21.22 μg/g), vanillic acid (22.27 μg/g), *p*-coumaric acid (9.57 μg/g), siring acid (10.42 μg/g), caffeic acid (8.63 μg/g) were detected and quantified in sumac leaves extract. These compounds have been associated with health benefits due to their antioxidant, inflammatory and anti-microbial properties among many others.

6.4 Tannins

Tannins (hydrolysable and condensed tannins) constitute the highest phytochemicals constituents in sumac parts like fruits, leaves and seeds. Among the two distinguished forms of tannins identified in sumac, hydrolysable tannins, mainly gallotannins are regarded as the characteristic property of sumac. Although hydrolysable tannins are still poorly characterized, they were reported to compose 20% of sumac fruits' mass. Interestingly, sumac represents one of the principal sources of hydrolysable tannins sold worldwide[11,33]. A study conducted by Romeo et al. on the extraction and identification of tannins showed six gallotannins including penta, hexa, hepta, octa, nona and decagallolyl-glucosides in sumac leaves and fruits. Moreover, 74 hydrolyzable tannins derivatives were identified in sumac[27]. The tannins extracts of sumac were found to possess antioxidant activity[34], and it is thought that the astringent taste of sumac is produced by tannin substances[27].

Tables 4
In vitro bioactivity.

Bioactivity	Source of sumac	Concentration (solid-to- liquid)	Composition	Method	Key findings	Reference
Fruit						
Antioxidant	Iran	NI	Determined by GC-MS: trans-Caryophyllene (7.84%), butanedioic acid (22.01%), 1,7-nonadien-4-ol, 4,8-dimethyl (1.06%), malate 39.7%, tricyclo[6.3.1.02,5]dodecane-8-ol (1.18%), cembrene (5.84%), palmitate (7.64%), 9-octadecenoic acid (2.61%), ethyl linoleic acid (4.04%) ethyl linoleolate (6.32%), and phytol (1.76%).	DPPH assay	The antioxidant activity of the extract increased with the increase in concentration. The antioxidant activity was higher than butylated hydroxytoluene	[69]
Antioxidant	Turkey	70% (*V*/*V*)	Phenolic acids determined by HPLC: Gallic acid (0.12–4.77 g/100 g), protocatechuic acid (0.04–0.41 g/100 g), p-OH-benzoic acid (0.09–0.81 g/100 g) and vanillic acid (0.05– 0.19 g/100 g)	DPPH assay	All extracts and fractions possessed strong radical scavenging activity at 30 μg/mL	[30]
Antioxidant	Iran	10:1 (mL/g)	Total phenolic conten: 0.811–3.277 mg GAE/g Total anthocyanins: 99.403–661.177 mg cyanidin3–3glucoside/g	DPPH assay	The maximum antioxidant capacity was noticed in brown sumac fruit and red sumac powder, which both showed significant DPPH values	[81]
Antioxidant	Iran	NI	content of tocopherols determined by HPLC: *α*-tocopherol 402.69 mg/kg, *γ*-tocopherol 45.63 mg/kg Phytosterol composition determined by GC: total sterols (4.42 ± 1.23), *β*-sitosterol, campesterol, cholesterol, and Δ7 -avenasterol were the main phytosterols.	- DPPH assay -FRAP assay	The values of DPPH radical scavenging FRAP were found to 75.95% and 66.93%, respectively	[82]
Antioxidant	UK	NI	Total polyphenol content : 176–5 384 g GAE/g	FRAP assay	Fresh Brown sumac was high in antioxidant activity and polyphenol content in all types of extractions compared with all other sumac types	[83]
Antioxidant	Turkey	NI	Total phenolic content: 1 058.57 – 1 470.00 mg GAE/kg. Fatty acids by GC: C16:0 (22.22%–24.41%), C18:0 (2.14%–2.75%), C18:1 (43.43%–48.44%), C18:2 (23.63%–30.34%) and C18:3 (0.77%–1.39%). Sterol by GC: Campesterol (6.95%–7.38 %), Stigmasterol (0.30%–0.52%), *β*-sitosterol (77.07%–78.51%), Sitostanol (0.50%–0.66%), Δ5-avenasterol (7.78%–9.17%), Δ7-avenasterol (1.16%–1.44%) and Δ7-stigmastenol (4.22%–4.55%). Tocol by HPLC: *α*-tocopherol (123.87–374.24 mg/kg), *γ*-tocopherol (154.24–183.02 mg/kg), *δ*-tocopherol (21.21–26.63 mg/kg), *γ*-tocotrienol (53.87–54.47 mg/kg) and *δ*-tocotrienol (5.47–7.92 mg/kg).	DPPH assay	The EC_{50} values of sumac fruit oil increased in parallel with the increase in the irradiation dose, that is, their antioxidant activities decreased	[5]
Antioxidant	Turkey	1:10 (*m*/*V*)	NI	-DPPH assay -DMPD assay	-the total reducing power of water extract was found higher than ethanol extract -Water extract of sumac (*R. coriaria* L.) scavenged radicals effectively with EC_{50} values of 36.4 μg/mL for DPPH free radical and 44.7 μg/mL for DMPD cation radical	[84]
Antimicrobial	Iran	NI	By using gas chromatography (GC/MS), the chemical compositions of the essential oil from the sumac fruit were examined : *trans*-Caryophyllene, Butanedioic acid, diethyl ester, 1,7-Nonadien-4-ol, 4,8-dimethyl, Malate, Tricyclo[6.3.1.02,5]dodecane-8-ol, Cembrene, Palmitate, 9-Octadecenoic acid, Ethyl Linoleic acid, Ethyl Linoleolate, Phytol.	micro dilution method	The extract shown substantial antibacterial properties. The most susceptible Gram positive and Gram negative bacteria were discovered to be *Staphylococcus aureus* and *Salmonella enterica*, respectively	[69]
Antimicrobial	Iran	1:10 (*m*/*V*)	NI	Broth microwell dilution susceptibility assay	-MIC (3.125 mg/mL) and MBC (6.25 mg/mL) value of sumac water extract against *S. aureus*	[85]
Antimicrobial	Iran	NI	Determined by GC-MS: *trans*-Caryophyllene (7.84%), butanedioic acid (22.01%), 1,7-nonadien-4-ol, 4,8-dimethyl (1.06%), malate 39.7%, tricyclo[6.3.1.02,5]dodecane-8-ol (1.18%), cembrene (5.84%), palmitate (7.64%), 9-octadecenoic acid (2.61%), ethyl linoleic acid (4.04%) ethyl linoleolate (6.32%), and phytol (1.76%).	Microdilution method	*Staphylococcus aureus*, *Salmonella enteric*, *Bacillus cereus* and *Escherichia coli* isolates showed the least to the highest resistance toward the extract, respectively. The MIC of the extract was lower than 1% (0.78%)	[12]
Antimicrobial	Italy	2:20 (*m*/*V*)	NI	Disk diffusion method	Sumac extracts exerted antibacterial activity against *S. aureus* ATCC 6538, and *E. coli* ATCC 25922	[4]

Table 4 (*Continued*)

Antimicrobial	Iran	1 500/1 (g/L)	Gas chromatography Mass spectrometry (GC-MS) was done to determine the chemical composition: *β*-caryophyllene (34.3%) and cembrene (23.8%) were the most frequently found constituents	Agar disk and agar well diffusion methods	*R. coriaria* with 2, 3 and 15 mg/mL concentrations prevented the growth of *Pseudomonas aeruginosa*, *E. coli*, *S. aureus* and *Bacillus subtilis*, respectively.	[44]
Seeds						
Antioxidant	Iraq	4.2%	NI	DPPH assay	-The radical scavenging effect at high concentration (75.0×10^{-6}) was: Methanolic, Ethanolic - Data also revealed that the- scavenging activity of each extract was increased with increasing the concentration.	[70]
Antioxidant	Iraq	1:10 (*m*/*V*)	NI	DPPH assay	- the extract radical scavenging capacity (EC50) values of pure tannin was (9 mg/ mL) - the pure tannin of sumac seeds is superior to BHT.	[86]
Leaves						
Antioxidant	Italy	1:6 (*m*/*V*)	NI	DPPH Assay	the extract from Sumac leaves was effective in reducing the stable free radical DPPH, and in vitro was able to contrast the harmful effects of IL-1β.	[71]
Antimicrobial	Italy	NI	NI		-The inhibitory action was high against both Gram-negative and Gram-positive bacteria - it was most active against *E. coli*. - for all other Gram-negative strains MIC values ranged from 312 mg/L to 625 mg/L.	[72]
Antimicrobial	Slovenia	20 g/L	HPLC was used to determine the sumac leaf extractives (gallic acid was identified as the predominant compound in the sumac leaf extract. The concentration of gallic acid was 4 g/L, representing 22.8% in terms of mass concentration of total extract).	ASTM E2149-01 standard procedure	- sumac leaf extract, showed excellent antibacterial activity against Gram-positive *S. aureus* with 99% bacterial reduction. - In contrast, the sumac leaf extract did not inhibit the growth of Gram-negative *E. coli*.	[73]
Antimicrobial	China	1:6 (*m*/*V*)	HPLC-QTOF-MS/MS was used to analyze the compounds in sumac leaves extracts (A total of 110 compounds were identified, including 10 urushiol compounds, 57 flavonoids and 43 other compounds)	- Minimum inhibitory concentrations (MIC) - Minimum bactericidal concentrations (MBC)	The MIC of light-harvested sumac leaf extract was about 0.31 mg/mL to all the six bacterial strains while the MIC of shading-treated sumac leaf extract were 0.31 mg/mL (*E. coli* and *S. aureus*) and 0.63 mg/mL (*S. pyogenes*, MRSA, *P. aeruginosa* and Kpneumoniae). - The MBC of sumac leaf extracts to the tested six bacteria were 0.63–5.00 mg/mL.	[74]

DPPH: 2,2- diphenyl-1-picrylhydrazyl. GC-MS: Gas chromatography-mass spectrometry. MIC: Minimum inhibitory concentration. MBC: Minimum bactericidal concentrations. NI: No information.

6.5 Volatiles compounds

It is well understood that aroma components are one of the most important factors that stimulate global food quality and consumers' preferences. Sumac, especially fruit has been reported to have many volatile components, which give its characteristic odor. Moreover, the essential oil extracted from sumac organs contain a significant number of volatile substances. Terpenes hydrocarbon comprising monoterpenes and sesquiterpenes were found to be the major volatile compounds detected in sumac fruits, leaves and essential oils[27]. Among the terpenes group, oxygenated monoterpenoids were also detected in significant amounts. They are known to contribute to the fruity odour of food materials[35]. The second major class of volatiles were quantitatively attributed to aldehyde, in which n-nonanal was the prominent aldehyde in sumac essential oils[36]. A study conducted in India revealed coririanaphthyl ether, coriarioic acid and coriariacthracenyl ester as new compounds in the plants[37]. Additionaly, Farag et al.[38] detected a total of 74 volatiles in sumac fruits obtained from Palestine, Jordan and Egypt and recorded α-pinene and *O*-cymenes as the main components. Research in Iran indicated E-caryophyllene as the dominant volatile component in sumac essential oil. The same authors highlighted the identification of 57 volatiles substances using GC-MS analysis[39]. E-caryophyllene was also reported as the major volatiles in sumac of Turkey[40-41].

6.6 Organic acids

Sumac, especially fruit possesses high contents of organic acid, including *L*-ascorbic acid, malic acid, and citric acid as major substances, while oxalic acid was reported as a minor compound[25]. The organic acids to some extent are responsible for the astringency and sourness taste of sumac fruits. Based on the earlier study, the amount of organic acids significantly varied within the sumac genotype, for instance, *L*-ascorbic acid accounted for 4.03–21.4 mg/kg, oxalic acid (1.3–2.9 mg/kg), citric acid (49.8–95.1 mg/kg), and malic acid (1 360–2 800 mg/kg)[25]. Malic acid and derivatives were recorded to be the most abundant organic acids in sumac[27]. In addition to the above mentioned organic acids, fumaric and tartaric acid were also recorded in low amounts in sumac fruits collected from Syria and China[41].

7. Biological activities

In recent decades, many studies on the biological activity of sumac extracts have been published. However, Sumac extracts have been demonstrated to have a variety of biological activities, which are explored in further depth below, and summarized in Table 4 and Table 5.

7.1 Antioxidant activity

The antioxidant activity of Sumac extracts has been studied extensively in several studies. Analysis of *R. coriaria* leaves

Table 5
Randomised control clinical trials investigating the health benefits of sumac based on a systematic search done through PubMed including all the clinical trials that have evaluated the health benefits of sumac through randomised controlled trials focusing on diseases or illnesses up to 27th Nov 2022.

Type of Study	Topic	Supplementation	Outcomes	Reference
Randomised double-blind placebo-controlled trial	Effect of sumac on patients with non-alcoholic fatty liver disease	Patients with the non-alcoholic fatty liver disease received 2 000 mg per day of sumac powder (n = 42) or placebo (n = 42) for 12 weeks. Both groups received a 500-calories deficit diet plan.	Supplementation with sumac resulted in a significantly higher decrease in hepatic fibrosis, liver enzymes, fasting blood glucose, serum insulin, HbA1c, insulin resistance index, malondialdehyde, and high sensitivity C-reactive protein, while it increased the insulin sensitivity index (P < 0.05). Thus, a daily intake of 2 000 mg sumac powder (with a low-calorie diet) for 12 weeks was helpful in managing the management of the alcoholic fatty liver disease	[75]
Randomised, triple-blind placebo-controlled crossover trial	Cardioprotective effects of sumac on patients with hyperlipidaemia	Patients (n = 30) with dyslipidemia received 500 mg/twice daily of sumac or a placebo for 4 weeks.	Supplementation with sumac resulted in a significant decrease in systolic and diastolic blood pressure, total cholesterol, and body mass index, and a significant increase in flow-mediated dilation (P < 0.05), with no effect on triglyceride levels. Thus, sumac consumption could lower cardiovascular risk factors in patients with mild to moderate hyperlipidaemia	[76]
Randomised, triple-blind placebo-controlled crossover trial	Cardioprotective effects of sumac on adolescents with hyperlipidaemia	Obese adolescents (n = 72) with dyslipidemia received 500 mg/three times a day of sumac or a placebo for a month.	Supplementation with sumac resulted in a significant decrease in f total cholesterol, low-density lipoprotein cholesterol, and triglycerides (P < 0.05), with no effect on high-density lipoprotein cholesterol	[77]
Randomised, double-blind, placebo-controlled clinical trial	Effect of sumac on patients with hyperlipidaemia	Patients (n = 80) with primary hyper-lipidemia received 500 mg/twice a day of sumac or a placebo for 6 weeks.	Supplementation with sumac resulted in a significant decrease in mean serum high-density lipoprotein cholesterol and polipoprotein-A1 levels (P < 0.05), with no effect on total cholesterol, low-density lipoprotein cholesterol and triglyceride levels	[78]
Randomised, double-blind, placebo-controlled clinical trial	Effect of sumac on anthropometric indices, oxidative stress, and inflammation in overweight or obese women with depression	Overweight or obese women with depression (n = 62) received a restricted calorie diet plus 3 g/day of sumac or placebo for 12 weeks.	Supplementation with sumac resulted in a significant decrease in weight, body mass index, body fat, visceral fat level, waist and hip circumference, and malondialdehyde levels (P < 0.05). Thus, sumac could help in obesity management, by the potential modulatory effects on oxidative stress	[79]
Randomised, single-blind, placebo-controlled clinical trial	Effect of sumac on patients with recurrent aphthous stomatitis	Patients with recurrent aphthous stomatitis (n = 22) received three pills (9 mm) of sumac (containing 50% Avicel as an ideal granulation binder, 0.2% magnesium stearate, and 49.8% *Rhus coriaria* powder) daily or triamcinolone (oral paste) for 6 days.	Treatment with sumac resulted in a significant decrease in lesion size (P < 0.05) of patients with recurrent aphthous stomatitis	[80]

extracts and fruit epicarp gave one of the highest antioxidant activity among all plants as the half-maximal inhibitory concentration (IC_{50}) of 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay was 0.02 mg/mL[42]. Furthermore, utilizing ferric thiocyanate and DPPH radical scavenging assays, methanolic extract of sumac demonstrated high antioxidant and scavenging activities. Sumac can be considered an effective natural antioxidant[29]. Another published research has examined the antioxidant activity of sumac fruit extracts that have been extracted with 80% methanol (*V*/*V*), and then an aliquot of each extract was further fractionated using n-hexane, ethyl acetate, and water. Results of the DPPH assay showed that ethyl acetate fraction of sumac methanolic extract had remarkable high antioxidant and higher free radical scavenging activity compared to the synthetic antioxidants butylated hydroxyanisole and butylated hydroxytoluene[9]. Further, sumac ethanolic extract showed high antioxidant activity, even higher than the effect of butylated hydroxytoluene[12]. Another research compared sumac fruit extracts to wild thyme and black thyme in terms of stabilizing food products like sunflower oil held at 70 °C and determining peroxide levels at regular intervals. Sumac extracts were shown to be the most effective in terms of sunflower oil stabilization[9].

In addition, in a study investigating the DNA-protective effects of Sumac extract in humans and animals. Sumac might prevent DNA damage by acting as a direct Reactive Oxygen Species (ROS) scavenger activity[43]. In the same study, the antioxidant effects of Sumac were found to be protective against inflammations and colon, liver and lungs cancers[43]. Recent interesting research by Heydari et al.[44] showed that sumac supplementation (500 mg twice daily) resulted in considerable weight loss, and reduction of waist circumference, and body mass index, along with a positive effect on insulin resistance in obese patients. Hence, the obtained results have been interpreted based on sumac high antioxidant and pancreatic lipase inhibition activities[43-45].

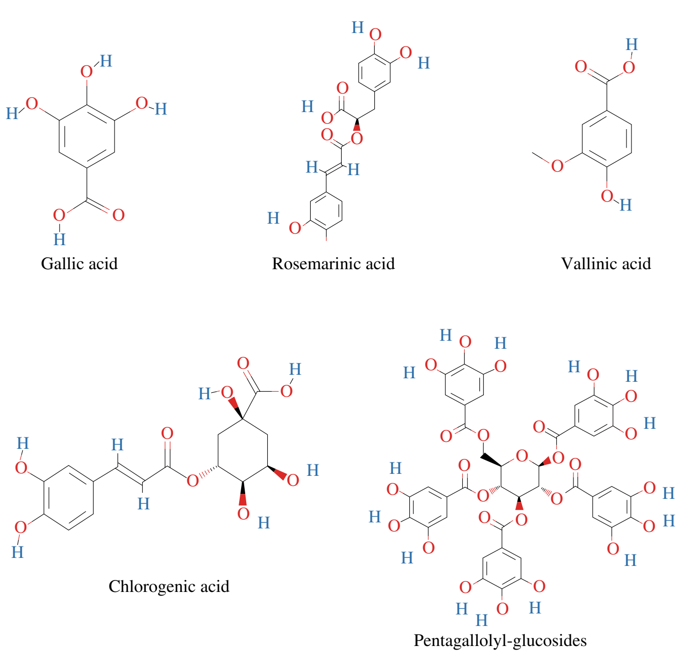

Fig. 3 Chemical structure of some phenolic acids compounds and tannin from sumac (PubChem).

7.2 Antibacterial, antifungal and antiparasitic activities

Sumac extracts are particularly well-known for their antibacterial properties[9]. Zhaleh et al.[44] have tested the antibacterial activity of sumac essential oil on a variety of bacterial strains. They reported that at doses of 2, 3, or 15 mg/mL, sumac essential oil effectively inhibits the growth of *P. aeruginosa*, *E. coli*, *S. aureus*, and *B. subtilis*. As though, the antimicrobial activity of sumac fruit ethanolic extract was evaluated against different gram-positive and gram-negative bacterial strains[12]. Results showed that *S. aureus* and *S. enteric* isolates were found to be the most susceptible to the ethanolic extract, with *B. cereus*, and *E. coli* isolates being the least sensitive[12-13]. In another recent study, the hydroalcoholic extract of sumac fruits showed bactericidal effects against *S. aureus*, *Enterococcus faecalis*, *P. aeruginosa*, and *Acinetobacter baumannii*[45].

The effectiveness of sumac in preventing tomato anthracnose, which is caused by *Colletotrichum acutatum* in tomatoes, was investigated. Surprisingly, an aqueous extract of Sumac fruits at a minimum inhibitory concentration (MIC) of 5 g/mL has substantial antifungal action against *C. acutatum*, which causes tomato anthracnose[13]. Singh et al.[37] found that methanolic extracts from sumac seeds had better inhibitory action against *Aspergillus flavus*, *Candida albicans*, and *Penicillium citrinum* at concentrations of 1, 5, 10, and 20 mg/mL, respectively[13,37]. Moazeni and Mohseni[48] carried out *in vitro* study on investigating the ethanolic extract of Sumac in the treatment of hydatid disease caused by the parasite *Echinococcus granulosus*. Results showed that the mortality rate of protoscolices increased to 98.89%, and 100% when they were exposed to a 30 mg/mL concentration of Sumac extract for 10 and 20 minutes, respectively[46].

7.3 Antinociceptive and anti-inflammatory activities

A published study investigated the analgesic benefits of Sumac hydro-alcoholic leaf extract have investigated in pre-treated Wistar rats[13]. A considerable reduction in writhing and pain has been reported. According to the findings, they concluded that the injection of rats with sumac extract (300 mg/kg) has a pain-relieving effect and can be considered a novel, natural, and safe compounds with an analgesic effect and hence deserves to be studied further in clinical studies[13]. On the other hand, the anti-inflammatory activity of ethanolic sumac extract has been examined by Khalilpour et al.[49].

7.4 Antidiabetic activities

In type II diabetic patients, the effects of sumac on serum glycaemic status, apolipoprotein (apo) B, apoA-I, and total antioxidant capacity (TAC) were investigated. Patients with type 2 diabetes who consumed 3.0 g of sumac powder daily for three months exhibited a considerable drop in blood glucose, haemoglobin A1c, ApoB, and ApoA-I levels, as well as an increase in total antioxidant capacity[13-14]. In another study on nicotinamide-streptozotocin-induced type 2 diabetic mice, Ahangarpour et al.[50] studied the antidiabetic and hypolipidemic effects of sumac seed extract. They reported that the administration of extract at the doses of 200 mg/kg and 300 mg/kg decreased level of glucose and cholesterol significantly in diabetic mice. Moreover, the LDL level decreased in diabetic mice treated with dose of 300 mg/kg of the extract.

7.5 Anti-ischemic activity

Beretta et al.[51] investigated the cardiovascular protective effect of sumac leaves extracts, by evaluating RFS (free radical scavenging), TNF- (tissue necrosis factor-) inhibition, cyclooxygenase pathway activation, and NO (nitric oxide) endothelial synthase activation in isolated rabbit heart. Their findings imply that sumac contains intriguing anti-ischemic hydrolysable gallotannins that are responsible for this pharmacological activity. Khalilpour et al.[49] proved the neuroprotective activity of the ethanol sumac extract.

7.6 Hepatoprotective activity

The hepatoprotective potential of Sumac extracts was also cited in the literature as one of its noteworthy biological actions. For instance, Pourahmad et al.[52] in their study, evaluated the protective effects of various doses of Sumac fruit aqueous extract (75 and 100 g/mL) and gallic acid (100 μmol/L) in isolated rat hepatocytes against oxidative stress toxicity produced by cumene hydroperoxide (CHP). According to the findings, both extract concentrations substantially protected the hepatocyte against all oxidative stress indicators[52]. Thus, in a recent review, they assumed that sumac consumption regularly may help in the treatment and/or prevention of metabolic syndrome and associated disorders such as non-alcoholic fatty liver disease (NAFLD), inflammation, cancer, and atherosclerosis[1].

7.7 Anticancer activity

According to the literature, sumac is one of the plants that has been shown to have anticancer properties against a variety of cancer types. For instance, in breast cancer; the cellular viability of several breast cancer cell lines (MDA-MB-231, MCF-7, and T47D) was shown to be reduced by sumac ethanolic extract (RCE) in a time and concentration-dependent manner[53]. Further, recently, sumac showed strong oncostatin activity in mouse models of breast cancer, which was confirmed *in vivo* and *in vitro* by mechanistic investigations[51]. Sumac has also been reported to show substantial anti-colon cancer efficacy by stimulating proteolysis and inducing autophagic and apoptotic cell death, making it a promising and useful source of new cancer therapeutics[52]. Likewise, sumac extract was proven the reduction of uterus cervix cell migration capacity. Sumac has a growth inhibitory effect on cervical cancer cells[13,53]. Latterly, Gabr and Alghadir[57] investigated the anticancer activity of Sumac against different human cancer MCF-7, PC-3, and SKOV3 cell lines. According to the results, Sumac suppressed the growth, multiplication, and viability of cancer cells at dosages of 50 and 100 μmol/L by triggering the apoptotic process via caspase-3 overexpression and the regulation of the anti-apoptotic protein Bcl-2[54].

The formation of new blood vessels conducted activated by the presence of vascular endothelium growth factor combined with other angiogenesis inducers formed the angiogenesis. Some hazardous effects may occur during this process. Therefore, its inhibition using plant extracts could contribute to the treatment and prevention of cancer and metastasis. For instance, the survey investigated by Sadeghi-Aliabadi et al.[58] using oleo gum resin methanolic extracts obtained from sumac showed anti-angiogenesis activity. The same authors concluded that the extract has proved cytotoxic and antiangiogenic activity against cancer cells and could probably be used as a natural anticancer product. Sumac organs have been proved to have antitumor activity, which was confirmed by many studies around the world. For example, the study conducted in Lebanon by El Hasasna et al.[53] using ethanolic extract of Lebanese sumac showed significant antiproliferative activity against MDA-MB-231, T47D, MCF-7, breast cancer cells. The authors revealed that T47D and MDA-MB-231 were more inhibited by ethanolic extract than MCF-7 cell lines. The same authors also demonstrated that sumac ethanolic extract protects DNA damage and mitigates mutant p53. Another study investigated highlighted the significant effect of sumac extract on colon cancer by inhibiting the colony growth of HT-29 cells and decreasing the rate of HT-29 tumour growth *in vivo* utilizing the mouse xenograft model. The authors concluded that sumac extract could be a potential preventive therapeutic product in breast and colon cancer treatment.

7.8 Cardioprotective and antihyperlipidemic activity

Sumac plant organs were also established to have cardiovascular activity. The research performed by Beretta et al.[51] utilizing methanolic extract of sumac leave demonstrated the capacity of extract to protect the rabbit heart through the activation of cyclooxygenase (COX) pathway, inhibition of tumour necrosis factor-α (TNF-α) and scavenging of free radicals and reactive oxygen species. Polygalloyloted *D*-glucopyranose with various degrees of gallolyation and 3-*O*-methyl gallic acid could be the bioactive fraction that exhibits cardiovascular activity against the aforementioned risk factors[51]. It is well understood that atherosclerosis development is associated with hyperlipidemia. Shafiei et al.[59] tested the effect of aqueous ethanolic extract obtained from sumac fruit on the rats administrated with high cholesterol diet, and the authors showed that the sumac extract was efficient to decrease high serum concentration, controlling and relieve some risk factors in hypercholesterolemic condition.

7.9 Anti-infertility activity

The human reproductive system can be influenced by any pathological alteration factors, which lead to different degrees of subfertility or absolute infertility. During the reproduction process, any small change in the structure of the molecules involved in the process could lead to abnormal dysfunction and detrimental effect on both, the male and female reproductive system[60]. It has been reported that one out of seven couples around the world is infertile[61]. The removal of molecular mediators in the reproductive system by reactive oxygen species (ROS) has tremendous effects on tissues damages with a high cell division rate in regular sperm release. The investigation conducted by Roshankhah et al.[62] demonstrated that sumac extract was able to alleviate the state of male infertility or subfertility. The authors indicated that sumac extract increases the level of TAC, inflammatory cytokine and testosterone, and inhibits the expression of p53 and caspase gene 3. Interestingly, the same authors stated that the intake of sumac extract can increase the fertility rate or restore infertility[63]. Administrated sumac extract at different concentrations with and without morphine to sixty-two male rats divided into 8 groups. Based on their data, the authors concluded that sumac extract can be used as a therapeutic medication since it was approved biochemically and histologically to scavenge morphine impacts.

7.10 Neuroprotective activity

Recent studies on the bioactivity of several plants or herbals containing natural antioxidants published in the literature seem to demonstrate the neuroprotective effect. For example, the *in vitro* assay carried out by Khalilpour et al.[49] to test the neuroprotective power mainly on retinal degeneration using ethanolic extract of sumac fruit showed that sumac extract greatly decreased serum-deprivation induced cell death of retinal ganglion cell (RGC-5). The authors also observed that sumac extract considerably eliminates the mitigation in the level of GST and GSH initiated by serum deprivation. Moreover, Gezici[64] investigated the in vitro neuroprotecitive effects of sumac extracts by evaluating their inhibitory activities on enzymes AChE and BChE at 25, 50, 100, and 200 μg/mL concentrations. The results showed that sumac extracts was found to have protective effects against the both of the enzymes at the tested concentrations, in which the water extracts of sumac were the most potent neuroprotector with the inhibition values of 28.62% ± 1.04%.

7.11 Antiprotozoal activity

Numerous drugs containing bioactivity effects have been used in the prevention or treatment of piroplasmosis infection caused by hepatotropic parasites. However, medicinal plants or herbals has recently emerged in the treatment of this infection thanks to their reduced side effects compared to synthetic one[65]. Some works showed that sumac organs have antiprotozoal activity against various piroplasmosis types of infections. The investigation conducted by Batiha et al.[65] using acetonic extract of sumac on 5 parasites such as Babesia bovis, Babesia bigemina, Babesia divergens, Babesia caballi, and Theileria equi revealed that sumac extract had a high growth-inhibiting effect against piroplasm parasites. The authors suggested that sumac extract could be used as a potential natural product against the multiplication of several piroplasm parasites both *in vitro* and *in vivo*.

7.12 Vasorelaxant properties

According to the recent studies on the vasorelaxation effect, The administration of sumac extract as an alternative medicine approach for the patients with various acute pathological conditions might have several beneficial effects, comprising the quality as a vasodilator, which has an immediate effect on cardiovascular protection[66]. The study performed by Anwar et al.[66] using sumac extract to evaluate the endothelium-dependent vasorelaxation of rat aorta indicated that ethanolic extract of sumac fruit, dose-dependently relaxes rat insulated aorta. The authors concluded that the finding supports the propitious potential use of sumac in cardiovascular protective action. Beretta et al.[51] examined endothelium-dependent vasorelaxant properties of hydrolysable tannins extracted from the leaves of sumac on insulated rabbit aorta rings precontracted with norepinephrine and with and without endothelium. Their results showed that the tannins obtained from the leave of sumac were able to stimulate relaxation in the isolated rabbit aorta rings and consequently as a potential remedy in cardioprotective action.

8. Safety

8.1 Toxicology

For efficient use of medicinal plants, an evaluation of their toxicity is essential to avoid cases of intoxication in case some of these plants could exhibit some adverse effects. To remain faithful to this principle, some toxicology studies were carried out on Sumac. The results showed that *R. coriaria* is safe for both humans and animals. In fact, Doğan and Çelik[67] studied the protective and therapeutic effects of sumac extract in rats with streptozotocin-induced diabetes. They tested the plant extract for toxicity at three different doses (250, 500 and 1 000 mg/kg). The results showed that even at very high doses (1 000 mg/kg), lyophilized sumac extract was best tolerated and non-lethal oral ingestion, with no signs of toxicity or mortality after daily administration of the extract for 3 days[64]. Furthermore, another study showed that oral administration of 300 mg/kg hydroalcoholic sumac seed extract had good results in controlling certain blood parameters in mice with type 2 diabetes without causing any adverse side effects[48].

Janbaz et al.[68], who demonstrated the antisecretory and antidiarrheal effects of crude extract of sumac in mice, reported that the extract was found to be safe even at a dose of 5 g/kg. A study conducted by El Hasasna et al.[53] also showed that chicken embryos treated with 150 μg/mL ethanolic extract of this plant were completely healthy, and this concentration was shown to inhibit tumor growth and invasion of breast cancer cells. Taken together, these results strongly suggest that this plant and its extracts are very safe, making them more attractive for medical use or drug research.

8.2 Interactions

To discover the relevant interaction potential of sumac, some studies have addressed the issue. Moazeni and Mohseni[48] have studied the scolicidal effect of the methanol extract of sumac as anthelmintic. Therefore, three concentrations of the plant extract (10, 30 and 50 mg/mL) were used for 10, 20 and 30 min, respectively. Whereas the 16.93% rate in the control group was for the dead protoscolices, the rate increased to 94.13%, 97.67% and 100% after 10, 20 and 30 min, respectively, obtained when the protoscolices were exposed to sumac extract at the concentration of 10 mg/mL. However, at the concentration of 50 mg/mL, a one hundred per cent (100%) mortality rate was observed after 10 min of exposure, suggesting that the methanol extract is an effective natural scolicidal agent. Moreover, the hypoglycemic efficacy of the plant extracts has been previously investigated by hindering the α-amylase enzyme. Ethyl acetate extract from sumac is considered to be beneficial in the treatment and prevention of hyperglycaemias and diabetes (IC_{50}: 28.7 mg/mL), indicating that sumac extract has considerable hypoglycemic activity, while methanol extract from fruits showed 87% inhibition activity at 50 μg/mL[69]. Ferk et al.[23] also reported that gallic acid intake of

0.2 mg/kg body weight per day in male rats for three consecutive days had protective effects on lymphocytes, brain, liver, large intestine and lung.

9. Future perspectives

Functional foods, in addition to providing basic nutrition, can have a positive effect on health and cure various diseases. The various articles reviewed on *R. coriaria*, which is well suited as a functional food, demonstrate this. *R. coriaria*, commonly known as sumac, is a commonly used spice, condiment, and flavouring agent due to its many beneficial values[43,65,70].

R. coriaria presents various pharmacological activities[65]. Qualitative phytochemical estimation revealed that it contains alkaloids, tannins, saponins, terpenoids, and significant amounts of flavonoids and polyphenols. Moreover, its richness in phenolic compounds, especially tannins and flavonoids, not to mention its abundance of organic acids are very beneficial for the body. The leaves and fruits of *R. coriaria* are known to have defensive and beneficial effects on a wide range of diseases, including, but not limited to, diabetes mellitus, cancer, stroke, oral diseases, inflammation, diarrhoea and dysentery. On the other hand, sumac extracts have been found to possess potential antiviral, antimicrobial, antifungal, antioxidant and hypolipidemic activities[10]. Sumac extracts are therefore potential and promising sources of functional ingredients and nutraceuticals with desirable bioactivities. Therefore, it is important to pursue the use of sumac in food preservation, pharmacology, public health, and health care. The popularization of the scientific results becomes therefore essential to make known the virtues of this plant and its application in functional foods. In addition, *R. coriaria* has recently been shown to have hepatoprotective, anti-ischemic, antimicrobial, and hypoglycemic and hyperlipidemic effects[10]. Due to its ease of collection and remarkable biological activities, *R. coriaria* can be used as both food and medicine. These results indicate the prospects of these extracts as drug candidates for the treatment of diseases after further studies in some clinical cases on the one hand and functional food on the other hand.

In addition, available information on sumac points to a wide range of its applications in traditional medicine for the management and treatment of many conditions and its therapeutic potentialities associated with its uses. It is therefore an attractive target for drug discovery[13]. Applied scientific research work in pharmacology is therefore desirable to make patients suffering from haemorrhoids, wounds, diarrhoea, ulcers and eye inflammations benefit from the virtues of this plant[13]. Cardiovascular diseases, diabetes and cancer are nowadays serious health problems that affect almost all social strata. The efficacy of the phytochemicals of *R. coriaria*, including flavonoids, tannins, and polyphenolic compounds, needs to be better demonstrated by science to confirm its bioactivity and its powerful antioxidant capacities that have beneficial and therapeutic effects on these diseases. Studies by Anwar et al.[66] have demonstrated the vasodilatory quality of *R. coriaria* that is concertedly channelled towards cardiovascular protection. Despite the benefits of the vasodilatory effects of sumac on the unhealthy circulatory system, there is little data on the mechanism of action of these vasodilatory effects. Therefore, it would be interesting to have advanced research done on the mechanism of action of these vasodilatory effects. Fazeli et al.[70] in their research work have shown that sumac traditionally used as astringent agents also shows promising inhibitory effects on food bacteria and could be considered a natural food preservative. Advanced research must therefore be carried out to enhance the use of this plant and take advantage of its virtues. Given the use of this plant as a spice, aromatic plant they could be of great use in industries and the fight against food poisoning caused by some synthetic flavours. Other industrial and therapeutic uses could also be sought by science. Advanced research must be done followed by popularization and stimulation of the use of this rather miraculous plant.

R. coriaria has been used for centuries as a spice, condiment, appetizer and acidifying agent with a wide range of phytochemical components of nutritional and medicinal importance and minerals that are beneficial in the treatment of various disorders and contribute to various biological processes. The reviewed articles have shown that this plant is used in traditional medicine in the treatment of diarrhoea, dysentery, ulcers, haemorrhoids, haemorrhages, wound healing, hematemesis, hemoptysis, leukorrhea, sore throat, ophthalmia, conjunctivitis, diuresis, animal bites, poison, pain and liver diseases with antimicrobial, abortifacient and stomach tonic abilities. Sumac has DNA protective, non-mutagenic, chondroprotective, antifungal, antibacterial, antioxidant, anti-ischemic, vasorelaxant, hypoglycemic, xanthine oxidase inhibition, vascular smooth muscle cell migration inhibition and hepatoprotective properties. However, there is little research data to correlate the therapeutic and dietary uses of *R. coriaria* with the chemical profile of the plant and the extracts used. Most studies only identify the type of extract and the part of the plant used but do not quantify the compounds present in the extract. It, therefore, has considerable potential for future research.

10. Challenges and shortcomings in the current researches

The current research on sumac faces significant challenges, limitations, and shortcomings, hindering a comprehensive understanding of its full potential. One major challenge is the limited number of scientific studies investigating sumac, despite its rich historical usage and cultural significance. The lack of in-depth investigations restricts researchers' understanding of sumac's mechanisms of action and its potential applications in various health conditions. Additionally, the variation in sumac species and chemical composition poses a significant limitation, as different species exhibit varying chemical profiles. This diversity makes it difficult to draw conclusive findings, with studies often focusing on different species or plant parts. Furthermore, inconsistencies in quality and sourcing complicate research efforts, as factors such as geographic origin, cultivation practices, and storage methods significantly influence sumac's chemical composition and potency. The lack of standardized extraction methods also hampers progress, hindering result comparability and reproducibility. Moreover, the limited number of well-designed clinical trials is a notable shortcoming, limiting our ability to translate preclinical findings into clinical practice effectively. Addressing these challenges and limitations will be crucial in unlocking the full therapeutic potential of sumac and advancing our understanding of its benefits and applications.

11. Conclusion

Due to the large variation in the bioactive and phytochemical content of sumac, sumac has a broad range of nutraceutical and pharmacological benefits. This makes sumac a rich functional food that can contribute to healthy living. In addition, the health promoting benefits associated with sumac can potentially increase its applications in different commercial products. More evidence and research are needed to explore the current nutritional benefits in humans through clinical trials. In fact, the more efforts could be applied to ensure that the phytochemical content of sumac is highly bioaccessible and bioavailable for more significant bioactivity. These efforts may be through encapsulating sumac and preparing different sumac formulations through complexation with other health promoting herbs or spices.

Conflicts of interest

None to declare.

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