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Phytochemistry, Pharmacological Properties and Industrial Applications of *Rhus coriaria* L. (Sumac)

Ibrahim M. Abu-Reidah, Rana M. Jamous and Mohammed S. Ali-Shtayeh[*]

Biodiversity and Biotechnology Research Unit, Biodiversity and Environmental Research Center-BERC, Til, Nablus, Palestine.

Abstract

Rhus coriaria L. (Sumac), belonging to the Anacardiaceae family, is an important species and is the most used species of the genus *Rhus* in the Mediterranean region since antiquity. Sumac has long been used as a flavoring spice, drink, appetizer, and as acidulant in food recipes, in addition to its use in traditional medicine. The role of the plant in leather and textile industry is also significant. *R. coriaria* is very rich in phenolics mainly and tannins as well as flavonoids; let alone its abundance with organic acids. The leaves and fruits of *R. coriaria* are recognized to have defensive and beneficial effects on a wide set of diseases, including, but not limited to, diabetes mellitus, cancer, stroke, oral-diseases, inflammation, diarrhea, and dysentery. On the other hand, Sumac extracts were found to possess a potential antiviral, antimicrobial, antifungal, antioxidant and hypolipidemic activities. This review updates the current phytochemical, biological and therapeutic knowledge that so far exists on *R. coriaria.* It also aims at highlighting the importance of Sumac extracts as a promising and potential source of functional ingredients and nutraceuticals with desirable bioactivities, prompting the further use of Sumac in food preservation, pharmacology and functional food industries.

Keywords: *Rhus Coriaria* L. (Sumac); Anacardiaceae; Pharmacology; Phytochemistry; Antioxidant, Antimicrobial, Tannins; Organic Acids.

1. Introduction

Rhus coriaria L. (Tanner's Sumac or Sicilian Sumac) (Figure 1) grows wild mainly in the Mediterranean bordering countries, South Europe, North Africa, Iran and Afghanistan (Nasar-Abbas and Halkman, 2004). The plant is also originated in temperate and tropical regions worldwide, often growing in areas of marginal agricultural capacity. Sumac is the common name of the *Rhus* genus, which comprises 91 of accepted species names in the Anacardiaceae (The plant list 2010). The name "Sumac" comes from "summāq" which means "dark red" in Arabic and Syriac (Quattrocchi, 1999). *Rhus coriaria* has been used in spice blends and in traditional medicines for hundreds of years (Ali-Shtayeh *et al.*, 2008). The word "sumac" will be henceforth used to indicate the spice product of *R. coriaria*.

Sumac has long been used as a seasoning spice, either in pure form or in combination with other spices, as a drink, appetizer, sauce, and also as a natural acidulant in food recipes (Abu-Reidah *et al.*, 2014). It is worth noting that *R. coriaria* has an attractive economic importance due to its increasing use in cosmetic and pharmaceutical industries, coloring or preservation of foods, veterinary practices and animal skins processing technology (Bahar and Altug, 2009; Kizil and Turk, 2010). In the past, the leaves, bark, roots and branches of *R. coriaria* were used in dyeing as mordant natural dyes. In addition, *R. coriaria* possesses high fixation, retention and fungal resistance properties, and is useful against wood decay (Sen *et al.*, 2009). So far, a big deal of nutritionally and medicinally considerable metabolites (such as phenolic acids, tannins, anthocyanins, organic acids, proteins, essential oils, fatty acids, fiber, and minerals) have previously been identified from various parts of *R. coriaria* (Shabir, 2012).

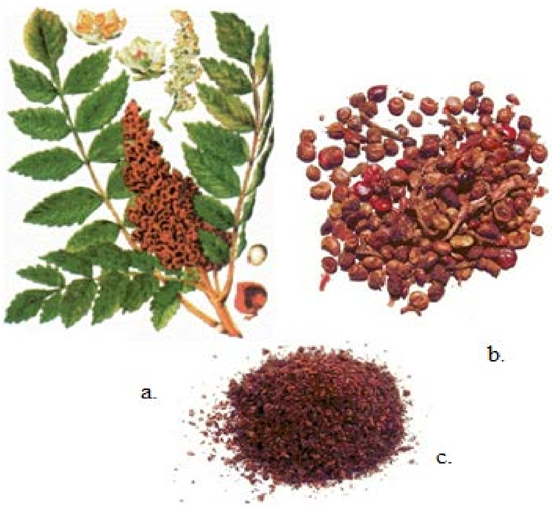

Figure 1. *Rhus coriaria* L. plant and fruits; a. Sumac plant (leaves, fruits, and flowers) b. Sumac fruits c. Sumac fruit powder.

[*] Corresponding author. e-mail: msshtayeh@yahoo.com.

Rhus coriaria has been reported to possess antibacterial (Aliakbarlu *et al.*, 2014; Kossah *et al.*, 2013; Ali-Shtayeh *et al.*, 2013; Iauk *et al.*, 1998), antifungal (Onkar *et al.*, 2011), antioxidant (Aliakbarlu *et al.*, 2014), anti-inflammatory (Panico *et al.*, 2009), DNA protective (Chakraborty *et al.*, 2009), vascular smooth muscle cell migration inhibition (Zargham and Zargham, 2008), hypoglycemic (Anwer *et al.*, 2013; Golzadeh *et al.*, 2012), and hypolipidemic activities (Madihi *et al.*, 2013). Moreover, this plant has traditionally and widely been used in the treatment of diabetes (Mohammadi *et al.*, 2010), stroke and cancer (Zargaran *et al.*, 2013), in the digestive tract maladies such as ulcer, diarrhea, stomach tonic, stomachache, and hemorrhoids pain (Ahmad *et al.*, 2013), diuresis, anorexia, measles, smallpox, hyperglycemia, gum ailments (Abu-Reidah *et al.*, 2014), hypertension (Polat *et al.*, 2013), atherosclerosis (Setorki *et al.*, 2012), dysentery, conjunctivitis, hematemesis, hemoptysis, and leucorrhea, dermatitis, ophthalmia, and liver disease, besides it was used also for throat treatment and in addition as abortifacient. Other medicinal uses have also been reviewed including weight loss, treatment of skin, hair, burns, digestive system, headache and temperature reducing (Ali-Shtayeh *et al.*, 2013). *R. coriaria* leaves have been reported to be useful in the treatment of chronic diseases as osteoarthritis and may form a potential application in joint disease therapy (Panico *et al.*, 2009). It was reported that the acute consumption of sumac might have a protective effect on some of the risk factors of atherosclerosis, oxidative stress and liver enzymes, due to high fat food stress (Setorki *et al.*, 2012).

The present review suggests increasing the size of research on and development efforts for obtaining bioactive whole extracts or individual functional components from *R. coriaria*, which makes the plant an appealing species of *Rhus*, as well as a source of functional food and nutraceutical ingredients. Additionally, it may help to further establish mechanisms of action of *R. coriaria* components, leading to a better understanding of the plant extracts and components' bioactivity. Moreover, this review attempts to focus on the traditional use of *R. coriaria* based on actual research data for its multivalent actions as health promoting dietary additives as well as putative therapeutic agents. In the current work, we critically review the so far known biological activities of *R. coriaria* extracts in an attempt to update the current knowledge on the plant.

2. History of Sumac use

Sumac has been used as a natural and traditional source of medication in different dietary cultures all over the world; the use of the plant in seasonings and flavoring agents has been the mainstay of indigenous remedies across the world.

Sumac is used as a spice, and has been used in cooking for millennia. About 2,000 years ago, the Greek physician Pedanius Dioscorides (40-90 A.D.) wrote in his voluminous "De Materia Medica" ("Of Medical Matters") about the healthful properties of Sumac, principally as a diuretic and anti-flatulent (Norton, 2006).

One practice of ancient Rome continues today in certain cuisines in which *R. coriaria* berries are pressed to extract their essential oils. The oil is then mixed with either olive oil or vinegar, depending on the type of condiment sauce being made. Nevertheless, the medicinal properties of *R. coriaria* had been noted since antiquity. For instance, sumac was used in folk medicine for the treatment of stroke chronic symptoms, as was described by Avicenna (Ibn-Sina) in his well-known book, *Canon of Medicine* (Zargaran *et al.*, 2013).

Interestingly, in Iran and Palestine, sumac represents pure ground fruit epicarps of the plant, while in Turkey the whole fruit is ground with salt crystals (Mirhadi *et al.*, 2011). It is commonly used as a seasoning spice in the Mediterranean region, especially in meat and fish dishes (Nasar-Abbas *et al.*, 2004). The ground sumac seeds, mixed with olive oil, are also used in food industry in salads and other meals (Kizil and Turk, 2010).

Today, a large mass of literature indicates that adding sumac into food stuff or water can have beneficial effects on human and animals (Chakraborty *et al.*, 2009).

3. Morphological Characterization of Different Parts of the Plant

Rhus coriaria L. is a shrub 3-4m high, the leaves pinnate with 6-8 pairs of small oval leaflets of different sizes, and white flowers in terminal inflorescences. The fruits are globose, villose and reddish drupe when ripe; with one seed, they contain tannins, essential oils, various organic acids, anthocyanins and fixed oil. The leaves contain gallic acid, (bi)flavonoid, sugar, wax and essential oils (Ünver and Özcan, 2010). Generally, investigations have focused on the tannin and flavonoid contents of *R. coriaria* leaves. Physical properties, such as length (4.70 mm), weight (0.20 g), volume (19.50 mm^3), geometric diameter (3.64 mm), sphericity (0.77), and thickness (2.64 mm) of *R. coriaria* fruits have been estimated at 4.79 % moisture content levels. At an identical moisture content level porosity (68.50%), static friction (0.48-0.68), bulk projected area (0.16 cm^3), terminal velocity (3.50 m/s), and density (304.25 kg/m^3) of the fruits were also determined (Özcan and Haciseferogullari, 2004).

4. Phytochemical Significance

In the light of the significance of sumac uses in food seasoning, folklore medicine and industry, *Rhus coriaria* has long been investigated to expose its chemical composition. *R. coriaria* plant is known as an abundant source of tannins (condensed and hydrolysable), phenolic acids, anthocyanins, gallic acid derivatives, flavonoid glycosides, organic acids (Abu-Reidah *et al*., 2014).

Parts like leaves, fruits, and seeds of *R. coriaria* were reported to contain a number of phyto-constituents as shown in Figure 2. The presence of gallotannins (mainly hydrolysable tannins) is a characteristic property of the *Rhus* genus, mostly *R. coriaria* species, which is an abundant source of tannins with different isomers and conjugations; besides, it contains other metabolites or phytochemicals, which have been described in various parts of the plant.

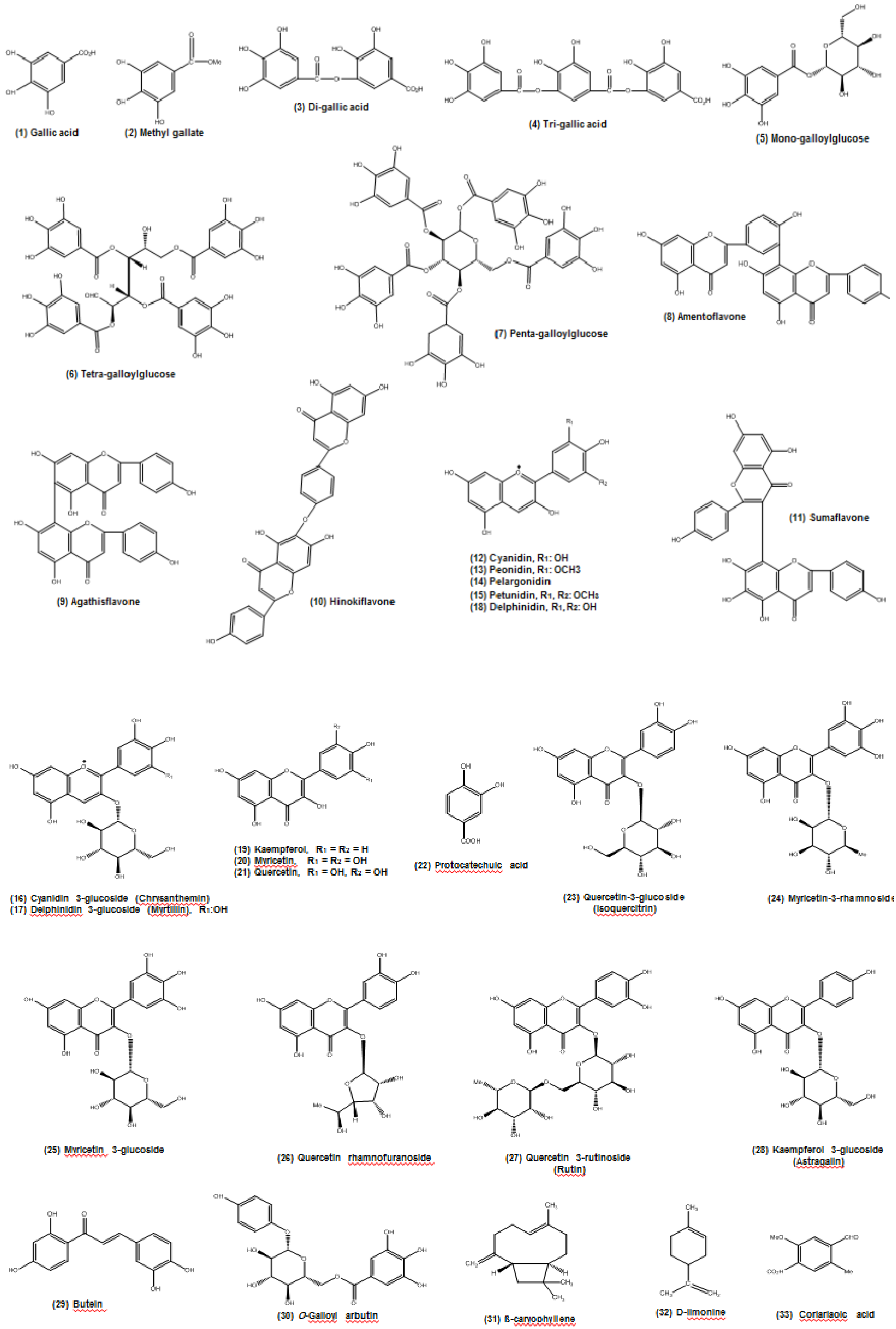

Figure 2. Structure of some selected phytochemicals from *Rhus coriaria*

Tannins are polyphenolic secondary metabolites of plants (MW's: 500 to 3,000), containing sufficient hydroxyls and carboxyls' groups (Haslam, 1989) which form hydrogen bonds in solutions. Tannins are astringent and bitter compounds, which can form strong complexes with various macromolecules that bind to and can precipitate proteins and other organic compounds including amino acids. They play a vital role in protecting plants from predation; and perhaps also as pesticides, as well as in plant growth regulation (Thorington and Ferrell, 2006). Lately, these substances have gained attention as they may trim down the risk of chronic diseases, by reinforcing the defenses against reactive oxygen species (Panico *et al.*, 2009).

The tannin compounds are widely distributed in many plant species, where they play a role in protection from predation, and plant growth regulation (Katie *et al.*, 2006).

Structurally, tannins are divided into two classes: hydrolysable and condensed ones. *Rhus coriaria* has been reported as one of the major commercial hydrolysable tannin sources (Sarioezlue and Kivanc, 2009).

The methanol extracts from *R. coriaria* fruits were reported as a rich source of natural antioxidants phenolics, mainly tannins, which has an inhibitory function in the migration of vascular smooth muscle cells, suggesting an atheroprotective role for this chemical. *In vitro* and *in vivo* studies have shown that tannins have anticarcinogenic effects (Ram *et al.*, 1997).

The aqueous and aqua-methanol extracts of *R. coriaria* leaves and fruits were investigated using HPLC to reveal the presence of gallotannins derivatives, namely gallic acid (1), methyl gallate (2), digallic acid (3), tri-gallic acid (4), and ellagic acid, together with mono- (5), di- , tri- , tetra- (6), penta- (7), …, deca-, undeca- and dodeca-gallolyl glycoside derivatives as representative tannins present in *R. coriaria* (Regazzoni *et al*., 2013). Some of the above-mentioned galloylglucose derivatives were reported to have the ability to reduce blood urea nitrogen and blood pressure (Djakpo and Yao, 2010).

In fact, the galloylated-glucose derivatives were previously studied in *R. coriaria* leaves using UV, paper chromatography, and IR measurements, in addition to the column chromatography technique which was used to uncover the existence of flavonoid glycosides (El Sissi *et al.*, 1972). Flavonoid dimers (with antiviral activity) like amenthoflavone (8), agathisflavone (9), hinokiflavone (10), and sumaflavone (11) have also been identified in the leaves and fruits via LC and LC-MS (Van Loo *et al.*, 1988; Abu-Reidah *et al.*, 2014). Other anthocyanins were also established: cyanidin (12), peonidin (13), pelargonidin (14), and petunidin (15) structures and coumarates, anthocyanins were peonidin-3-glucoside, petunidin-3-glucoside (coumarate), delphinidin (coumaroyl) glucosides, and cyanidin coumaroyl glucoside. However, the presence of cyanidin-3-glucoside (16), delphinidin-3-glucoside (17) and delphinidin (18) has already been reported from the fruits of *R. coriaria* (Mavlyanov *et al.*, 1997).

Furthermore, some other phenolics have been isolated from *R. coriara*, including gallic acid, methyl gallate, kaempferol (19), myricetrin (20), quercetin (21), *p*-benzoic acid, vanillic acid isoquercitrin, protocatechuic acid (22), kaempferol 3-galactoside, quercetin 3-glucoside (isoquercitrin) (23), quercetin 3-rhamnoside, myricetin 3-rhamnoside (24), myricetin 3-glucoside (25), myricetin 3-glucuronide, myricetin 3-rhamnoglucoside, have also been already identified in the *R. coriaria* leaves and fruits (Shabana *et al.*, 2011; Abu-Reidah *et al.*, 2014). The separation of gallotannins and flavonoids was carried out by HPLC-ESI-MS, which allowed the structure resolution of the isobaric flavonoid glycosides.

Lately, a detailed profiling of phytochemical compounds has been carried out by analyzing the hydromethanolic extract of the fruits using HPLC-DAD-ESI-MS/MS technique, where more than 200 phytochemical components have been tentatively identified. Curiously, the occurrence of the conjugated form of aglycone with hexose-malic moieties (24 compounds) has been very recently identified for the first time in the Palestinian *R. coriaria* (Abu-Reidah *et al.*, 2014). In the same work, five cyanidin derivatives have been newly detected anthocyanins in the fruit epicarps. Moreover, the following flavonoid glycosides have been also identified: quercetin-rhamnofuranoside (26), rutin (27), and kaempferol 3-glucoside (Astragalin) (28).

Butein (29) is a recently identified chalconoid derivative from *R. coriaria*. Notably, this compound exhibited a significant anti-breast cancer activity (Li *et al.*, 2014). Another galloyl derivative compound was also characterized in the fruits: *O*-galloyl arbutin (30).

Minerals are essential chemical elements for supporting the human health, indispensably obtained from the diet. Once minerals intake is inadequate, deficiency symptoms may take place (McDowell, 2003). However, minerals like potassium, calcium and magnesium were found to be predominant in sumac. Other minerals have also been explored, namely sulfur, cadmium, phosphor, lead, titanium, vanadium, copper, silicon, barium, chromium, lithium, brome, aluminum, chloride, manganese, iron, sodium, zinc, strontium, and nitrogen (Kizil and Turk, 2010).

On the other hand, β-caryophyllene (31) a bicyclic sesquiterpene has been recently described to be a major essential oil component isolated from *R. coriaria* (Gharaei *et al.*, 2013). An anti-inflammatory effect for this terpenoid has been described elsewhere (Gertsch *et al.*, 2008).

Interestingly, *R. coriaria* fruits were found to possess various fatty acids, including azelaic, tetradecanoic, elaidic, stearic, eicosadienoic, arachidic, and tetracosanoic acids, with oleic (ω 9), palmitic, and linoleic (ω 6) acids being as major fatty acids in sumac. The polyunsaturated fatty acid (ω 6+ ω 3) contents of the total fatty acids were found to be between 34.84 and 37.36% (Dogan and Akgul, 2005). The main fatty acids of sumac were found to be: oleic (33.78-52.57%), palmitic (17.00-29.80%), linoleic (11.60-21.90%), linolenic (0.33-1.33%) and stearic (17 %) acids. On the other hand, linoleic (49.35-60.60%), oleic (24.60-32.05%), palmitic (8.30-13.60%), stearic (1.60-3.00%) and linolenic (0.46-0.74%) acids were described to be major fatty acids of *R. coriaria* seeds (Ünver and Özcan, 2010).

It is worth noting that the major volatiles determined from *R. coriaria* were aliphatic, farnesyl acetone, aldehydes, hexahydrofarnesylacetone, and oxygenated terpenes, among others. Terpene hydrocarbons were reported to be the main constituents. Polyisoprenoids from the leaves were investigated via GC–MS (Mamatkulova *et al.*, 2012). A-tocopherol was found as the predominant existing substance; besides, other minor components, such as tocopherol mannoside, farnesylacetate, pentadecanal, and hexadecanal, have also been determined. D-limonene (32), a monoterpene derivative isolated from the plant, was found to have hypocholesterolemic effects (Golzadeh *et al.*, 2012). A recent study reported that cembrene (21.40 %) and β-caryophillene (30.70 %), as main terpinoid derivatives, are found in *R. coriaria* (Gharaei *et al.*, 2013).

However, the sourness of sumac is mainly due to the presence of organic acids, such as malic, citric and tartaric acids (Kossah *et al.*, 2013), while the astringent taste is ascribed to its tannins composition. It is interesting to know that *R. coriaria* fruits and seeds are incredibly rich in antioxidants, Vitamins A and C.

5. Biological Properties

Many literature reports indicate that the addition of sumac to the food/feed or water can impart a beneficial effect on both human beings and animals (Capcarova *et al.*, 2012). Some of the recently published information about the biological activities in literature is illustrated in Table 1.

Table 1. Digest of reported biological activities of different used parts of *Rhus coriaria* L.

Pharmacological Properties	Plant part used	Used extract/plant part (form)	Result/Activity	Reference
Antibacterial activity	**Fruits**	Hydrodistilled extract	Demonstrated a desirable antibacterial activity	Sağdıç, and Özcan, 2003
	Fruits	Ethanol and methanol extracts	Sumac extracts were effective against Gram positive and Gram negative bacteria	Nasar-Abbas and Halkman, 2004
	Fruits	Ethanol 95% extract	Significant antibacterial activities against all tested species have been shown	Nimri,*et. al*., 1999
	Fruits	Methanol extract	A strong *in vitro* antioxidant activity indication of the methanolic extract of sumac fruits	Candan, and Sökmen, 2004
	Fruits	Water extract solution extract 0.8:10 (wt/vol)	Bacteriostatic/bactericidal effects by bacteria cycle reduction exerted by sumac extract have demonstrated	Gulmez, *et al.*, 2006
	Plant	Water, Methanol 80 %, Ethanol 80 % extracts	Antibacterial activity can be exerted individually or conjointly with other spice	Adwan, *et. al*., 2006
	Fruits	Ethanol 80% extract	Effective antibacterial agents on both Gram-positive and Gram-negative bacteria	Fazeli *et al*., 2007
	Plant	Ethanol extract	*R. coriaria* extract can have an antimicrobial effect on total microbial and *Salmonella* count in minced meat for one week	Radmehr and Abdolrahimzade, 2009
	Leaves	Ethanol 95% extract	Showed a high antibacterial activity in comparison with other plants	Ertürk, 2010
	Plant	Ethanol 80% extract	Sumac extracts exhibited a moderate activity on *Brucella* strains	Zandi, *et al.*, 2012
	Fruits	Ground and fermented sumac	*R. coriaria* could decrease the formation of biofilm, a major virulence factor in staphylococcal infections	Kırmusaoğlu, *et al.*, 2012
	Plant	Ethanol extract	Results indicated that among other plant extracts, the sumac one, was found to have the most potent against: *Propionibacterium acnes*, *S. aureus*, *E. coli*, *P. aeruginosa*	Ali-Shtayeh, *et al.*, 2013
	Fruits	Ethanol 20% extract	A remarkable inhibitory activity was shown by sumac extract against *B. cereus*. Also it strongly inhibited the growth of *H. pylori*. The fruit extract exhibited a good antioxidative capacity, justifying its use as a natural antibacterial preservative	Kossah, *et al.*, 2013
	Plant	Water extract	Sumac water extracts showed the strongest antibacterial activity among other 10 extracts studied.	Aliakbarlu, *et al.*, 2014; Aliakbarlu, *et al.*, 2014
Antioxidant activity	**Fruit epicarps**	Methanol extract	From results it can be noted a desirable antioxidant activity of sumac which in turn could delay the oxidation of palm oil	Ozcan, 2003
	Plant	Ethyl acetate and 80% methanol fractions after initial defatting by petroleum ether	The ethyl acetate fraction of plant materials exhibited a noticeable antiradical activity on DPPH	Bozan, *et al.*, 2003
	Fruits	Methanol extract	Results indicate a strong *in vitro* antioxidant activity of the methanolic extract of *Rhus coriaria* fruit based on hydroxyl radical scavenging	Candan , 2003

Pharmacological Properties	Plant part used	Used extract/plant part (form)	Result/Activity	Reference
	Fruits	Water extract	Sumac extract was more effective than BHT, and could be added to meat products (e.g. sausage)to enhance quality	Bozkurt , 2006
	Fruits	Methanol 70% extract	Sumac extracts and fractions showed remarkable antioxidant activity against inhibition of lipid peroxidation and scavenging activity based on DPPH radical assay.	Kosar, *et al.*, 2007
	Aerial parts	Methanol 50% extract	A desirable antioxidant activity was shown	Serteser *et al.*, 2009
	Fruits	Ethanol and water extracts	Water extracts of sumac with effective antioxidant and radical scavenging activities as compared to ethanol extracts.	Bursal and Köksal, 2011
	Fruits	Ethanol 20% extract	Sumac fruit extract exhibited a good antioxidative capacity also it showed a remarkable inhibitory activity against *B. cereu*, besides it strongly inhibited the growth of *H. pylori*.	Kossah, *et al.*, 2013
	Plant	Water extract	Sumac water extracts showed the strongest antioxidant activity among other 10 extracts	Aliakbarlu, *et al.*, 2014
Antidiabetic activity	**Fruits**	Methanol extract after fractionation with ethyl acetate and hexane	Ethyl acetate fraction of sumac fruits showed appreciable biological activity through α-amylase inhibition indicating significant hypoglycemic activity.	Giancarlo, *et al.*, 2006
	Fruits	Ethanol 96%	The Sumac extract raised markedly HDL and also reduced LDL, increasing superoxide dismutase and catalase activities. Also, it inhibited maltase and sucrase activities.	Mohammadi, *et al.*, 2010
	Fruits	Ethanolic extract	Antidiabetic activity in vivo: Alloxan-induced diabetic wistar rats	Sharma and Arya, 2011
	Seeds	Methanol extract	Antidiabetic effect of Sumac on blood glucose and glycosylated hemoglobin levels in NIDDM rats.	Anwer *et al.*, 2013
DNA-Protect activity	**Fruits**	Sumac extract in water solution	Sumac showed to be a potent antioxidant which may protect humans against oxidative DNA-damage suggesting gallic acid as main contributor for Sumac effects	Chakraborty *et al.*, 2009
Lipid-lowering and hypocholesterolic activity	**Fruits**	Methanol 80% and 100% extracts	Sumac fruit extract was of use in decrease the high serum lipid levels, and moderate the elevated cardiac lipid concentrations.	Shafiei, *et al.*, 2011
	Fruits	Dietary supplement Sumac fruits, and methanol 80% extracts	Decrease in cholesterol in the blood of rabbits resulted after the oral administration of sumac during 90 days, showing thus a positive effect on cholesterol and VLDL levels in adult male rabbits.	Capcarova *et al.* 2012
	Fruits Powder	Dietary Sumac powder oral administration	Dietary supplementation of sumac, reduces the blood VLDL-c, TC, and FBS concentrations in broiler chicken	Golzadeh, *et al.*, 2012
	Fruits Powder	Fat diet with 2% of Sumac powder	A protective effect of consuming sumac with food on some risk factors of atherosclerosis and oxidative stress (LDL-C, total cholesterol) has been demonstrated	Madihi *et al.*, 2013
	Fruits	Dietary Sumac powder oral administration	Sumac can be useful to decrease the negative effects of mild heat stress on broiler chickens due to its richness in tannins.	Alishah, *et al.*, 2013
Antimigratory activity	**Fruits**	Acetone 70% extract	Tannin extract from Sumac has an inhibitory role on the migration of VSMC and suggesting an atheroprotective role.	Zargham and Zargham, 2008
	Fruits	Dietary Sumac powder oral administration	Acute consumption of Sumac might be having protective effects on some risk factors of atherosclerosis, and liver enzymes, due to high fat food stress.	Setorki, 2012
	Leaves	Ethanol extract	Moderate antifungal activity was found for Sumac	Ertürk, 2006

5.1. Antibacterial and Antifungal Properties

It is worth mentioning that a large number of antibacterial activity studies have specifically focused on sumac because of its wide-range use in the Mediterranean area as a seasoning spice.

Most of the antibacterial assays carried out on *R. coriaria* used either ethanol or water extracts. In this context, the water and hydro-methanol extracts from the fruits were found to have a great activity against more than 10 different bacteria species, among which are Gram positive and Gram negative bacteria strains, *Staphylococcus aureus*, *Escherichia coli*, *Bacillus cereus*, *Yersinia enterocolitica*, *Shigella dysentariae*, and *Salmonella enteritidis* (Nasar-Abbas and Halkman, 2004). Among several plants tested, the aqueous extracts of sumac had the strongest antibacterial activity against the tested bacteria (Aliakbarlu *et al.*, 2014). According to Gulmez *et al*. (2006), the water extract of *R. coriaria* fruits had an antimicrobial activity against coliform applied on the stored poultry meat. It is worth noting that the mature fruits of *R. coriaria* possess higher antimicrobial activity in comparison to the immature ones.

The ethanol extract of sumac was reported to be effective in count-decreasing of the total microbial count and salmonella in the minced meat, in which a significant antimicrobial potential was shown for the ethanol extract compared to controls (Radmehr and Abdolrahimzade, 2009). Furthermore, the methanol extract of sumac fruit demonstrated an important antibacterial activity against *Bacillus pumilus*, *Bordetella bronchiseptica*, *Staphylococcus epidermidis*, and *Klebsiella pneumonia*, using the agar well-diffusion method (Shabir, 2012).

The antimicrobial activity of *R. coriaria* extracts were tested against six strains, including three Gram-positive and three Gram-negative. *Bacillus subtilis* was found to be the most sensitive Gram-positive with MIC of 0.5 mg/ml, while Gram-negative bacteria were affected by higher concentrations of sumac extracts ranging 10-20 mg/ml. Among bacteria, the inhibitory effects increased with the increase of *R. coriaria* fruit extracts concentration from 0.1 to 20 mg/ml (Raodah *et al*., 2014). The antibacterial activity of the plant extract against *Brucella* has been also assessed, in which the mean zone of growth inhibition for Sumac was 22.55 mm for disks that contained 40 mg/mL, and (MIC: 3.26 mg/mL), whilst the minimum bactericidal concentration (MBC) was 9.03 mg/mL (Motaharinia *et al.*, 2012). The antibacterial effect of *R. coriaria* on the biofilm formation of *S. aureus* has been also evaluated. Significant differences between varying concentrations of the plant extract were observed in several strains of methicillin resistant/sensitive *S. aureus*, indicating dose-related diminishes in the slime formation noted in bacteria. Briefly, the plant extract could reduce the formation of biofilm, a major play factor in staphylococcal infections (Kırmusaoğlu *et al.*, 2012). Among the fifty Palestinian medicinal plants that were examined to investigate their antimicrobial activities against acne *vulgaris*, the ethanolic extract of *R. coriaria* exhibited a strong inhibitory effect and was found to be among the most active plant extracts against all bacterial strains tested including, *P. acnes*, and Gram-negative strains of aerobic bacteria (Ali-Shtayeh *et al.*, 2013). It is worth mentioning that the observed *in vitro* antimicrobial potential of *R. coriaria* has been mainly referred to the presence of tannins.

On the other hand, the antifungal activity results, reported by Onkar and coworkers (2011), have indicated that the sumac methanol extract, including other three individual compounds (coriorianaphthyl ether, coriariaoic acid, and coriarianthracenyl ester) thereof, were found to be able to reduce the growth of several fungus strains. Thus, coriariaoic acid (33) was effective against both *A. flavus* and *C. albicans* at the lowest tested concentration of 25 mg/ml, analogous to the standard (Fluconazole) at higher tested concentrations against *A. flavus*, unlike the case of *C. albicans*. Moreover, coriarianaphthyl ether has exhibited a comparable activity at higher concentrations of the reference drug; it was also found to be active against all the fungal strains tested at all concentrations used (Onkar *et al.*, 2011). In one more study, it was shown that the alcohol extract of *R. coriaria* to possess a high antifungal activity against *C. albicans* and *A. niger* (Ertürk, 2010).

From the results given about the antimicrobial and antifungal activities, it can be concluded that the aqueous and alcoholic extracts of *R. coriaria* possess compounds with valuable antibacterial and antifungal activities that can be potentially used as antimicrobial agents and in the treatment of infectious diseases including acnes and those caused by resistant microorganisms.

5.2. Antiviral Activity

The antiviral activity of twenty five species of various medicinal plants in Iran was investigated, of which the aqueous extract of *R. coriaria* exhibited a significant antiviral activity against HSV-1 and adenovirus type 5 at non-toxic concentration (Monavari *et al*., 2007).

Interstingly, four biflavones, viz. amentoflavone (8), agathisflavone (9), hinokiflavone (10), and sumaflavone (11), were isolated from the leaves and fruits of different *Rhus* species. Amentoflavone (8) and agathisflavone (9) have shown an activity against influenza A and B viruses. Amentoflavone exhibited moderate anti-HSV-1 and anti-HSV-2 activities with EC50 =18 and 48 μg/mL, respectively (Lin *et al.*, 1999). On the other hand, hinokiflavone, amentoflavone, and agathisflavone demonstrated significant activities against HIV-1 reverse transcriptase, with IC_{50} values ranged from 65-100 μM (Lin *et al.*, 1997). In a previous work, hinokiflavone isolated from *Podocarpus macrophyela* has shown an antiviral activity demonstrated by its inhibitory action noted on the Epstein-Barr virus genome expression in Raji cells, which suggested an important antiviral potency of this biflavone (Kozuka *et al.*, 1989).

5.3. Antioxidant Activity

Antioxidant activity of *R. coriaria* fruit methanol extract against lipid peroxidation and free radicals has been previously reported indicating that the plant extract may prevent the development of chronic diseases such as atherosclerosis (Shafiei *et al.*, 2011). On the other hand, Aliakbarlu *et al.* (2013) studied the antioxidant activity of water extract of sumac among other spices and found that the water extracts of the plant have one of the highest antioxidant potential among the extracts studied.

The results of antioxidant activities indicated that the antioxidant effects are due to phenolic components, especially, gallic acid and its derivatives (Chakraborty *et* *al.*, 2009). Ferk and coworkers (2007) estimated the antioxidant effect of sumac to be 50 fold more than vitamin C and E. Besides, they reported that the daily consumption of 0.2 mg per kg body weight gallic acid for three days, in male rats, showed protective effects on lymphocytes, brain, liver, colon and lung.

In a very recent study, Gabr and coworkers (2014) extracted the active constituents of sumac like, alkaloids, glycosides, phenol and terpenoids using GC-MS. The antioxidant activity of *R. coriaria* extract and its constituents were determined using DPPH and β-carotene-linoleic acid scavenging activity assays. Antioxidant activity showed a range of (72.70-87.9%) for the plant extract compared to a lower antioxidant activity of its active constituents. However, phenols showed a higher range of antioxidant activity (70.1-75.8%) compared to glycosides (65.7-67.6%), alkaloids (53.4-58.4%) and terpenoids (50.7-51.3%), respectively (Gabr *et al*., 2014).

Antiradical activities of water and ethanol extracts of *R. coriaria* were studied comparatively. The study indicated that antioxidant capacity and radical scavenging of water extract was significantly higher than that of ethanol extract. Also, amounts of both total phenolic and total flavonoid contents of water extract were higher than those of ethanol extract (Bursal and Köksal, 2011).

5.4. Antidiabetic Activity

Diabetes mellitus is a metabolic disorder of the endocrine system which is emerging as a severe problem. It continues to increase both in numbers and in the impact upon the quality of life, as changing lifestyles leads to reducing physical activity and to increasing obesity. In 2010, 285 million adults worldwide were estimated to have DM (approaching 7% of the adult population). It is anticipated that by 2030, the number of DM patients will exceed 438 million people, almost 8% of the adult population (Ali-Shtayeh *et al*., 2012). The fruits could improve the life of type 2 diabetic patients by exerting mild antihyperglycemic and potent antioxidant properties. Moreover, *R. coriaria* is highly recommended for the blood lipids adjustment in diabetic patients.

The hypoglycemic efficacy of the plant extracts has been previously investigated via hindering the α-amylase enzyme. Ethyl acetate extract of sumac was suggested as beneficial in the treatment and prevention of hyperglycaemias and diabetes (IC_{50}: 28.7 mg/mL), suggesting a considerable blood sugar decreasing activity of sumac extracts, whereas, the methanol extract of fruits showed 87% inhibition activity at 50 μg/mL (Mohammadi *et al.*, 2010).

Another study carried out by Anwer *et al.* (2013) suggested that the methanol extract of *R. coriaria* can notably delay the onset of hyperinsulinemia and glucose intolerance, and it can also improve insulin sensitivity in rats. Above all, the gallotannin; penta-galloylglucose (7) which was repeatedly reported in sumac plant was found to have an antidiabetic effect, exhibited by acting as an inhibitor of PTP1B enzyme (Baumgartner *et al.*, 2010). In contrast to this, it was found, by other researchers, that the plant extracts increase the levels of blood sugar in rats (Mirhadi *et al*., 2011; Pashazadeh *et al*., 2013). These findings demonstrate that sumac can positively affect the blood sugar level in diabetic patient.

5.5. Hypolipidemic Activity

Positive effects of sumac consumption on antioxidant status and cholesterol level in rabbits have been demonstrated in a recent study, suggesting that the plant may have a lowering effect on blood cholesterol level in animals and human beings (Capcarova *et al.*, 2012; Golzadeh *et al.*, 2012). On the other hand, Shafiei and coworkers (2011) showed that the sumac extract was able to decrease high serum lipid concentrations and could adjust the elevated cardiac lipid levels in the hypercholesterolemic conditions.

Additionally, Valiollahi and others (2014) have shown that the triglyceride and cholesterol level decreased significantly in broiler chicks that consumed sumac; also, the LDL level decreased significantly and HDL levels increased in the same group (Valiollahi *et al*., 2014). Similarly, Santiago *et al.*, (2010) reported reduced serum cholesterol concentrations in rats consuming d-limonene. It was recently monitored that the acute consumption of sumac might have a protective effect on some of the risk factors caused by high fat food stress, such as atherosclerosis, oxidative stress and liver enzymes (Setorki *et al.*, 2012). Again, a significant decrease in the blood levels of total cholesterol, LDL-C, and fibrinogen compared to the high-cholesterol diet group have been described elsewhere (Madihi *et al.*, 2013), a protective effect demonstrated on some risk factors including atherosclerosis and oxidative stress, followed consuming the Sumac with food.

5.6. Scolicidal Activity

In nature, only few anthelmintics are available for healing hydatid disease caused by the parasite *Echinococcus granulosus.* Lately, Moazeni and Mohseni (2012) have studied the scolicidal effect of the methanol extract of sumac as anthelmintic. Thus, three concentrations of the plant extract (10, 30 and 50 mg/mL) were used for 10, 20 and 30 min. Whereas 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 minutes, 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, one hundred percent mortality rate was observed after 10 min of exposure, suggesting the methanol extract to be an effective natural scolicidal agent.

5.7. Anti-Mutagenic Activity

Chakraborty *et al.* (2009) have suggested that *R. coriaria* can protect against genotoxic carcinogens, which are degraded by specific enzymes, namely glutathione S-transferase GST–π, and GST-α were clearly enhanced by 40%, 26%, and 52%, respectively. Actually, gallic acid, a major constituent of the plant, is known to possess multiple biological activities, including anticancer function (Liu *et al.*, 2011). However, this work indicated an inhibitory role of invasion and migration of PC-3 cell dose-dependently of gallic acid. Consequently, it was postulated that the gallic acid might modulate in the course of blocking the several signaling pathways and dropping the NF-κB protein level, resulting in human prostate cancer cells inhibition.

Hinokiflavone (10) has been previously characterized as the cytotoxic principle from *R. succedanea* and *R. coriaria* berries; however, its significant cytotoxicity was referred to the ether linkage between the apigenin aglycones (Lin *et al.*, 1989).

6. Applications of Sumac in Food Safety and Technology

There is an increasing interest in using plant extracts by the food industry as natural preservatives. Lipid oxidation and microbial growth in food can be controlled by the use of plant extracts. Water extracts of *R. coriaria* possess a strong antioxidant and antibacterial activity against food-born pathogenic bacteria, suggesting the use of water extracts of the plant as effective and natural preservatives in food manufacturing (Aliakbarlu *et al.*, 2014). Industrially, the seeds are by-products in the production of the spice; however, they are rich in linoleic and oleic acids that qualify the plant seeds to be considered as a valuable raw material for the oil industry. In this context, the mixing of *R. coriaria* seeds oil with olive oil for the use in salads and cooking has already been proposed (Ünver and Özcan, 2010).

The plant extract has shown to be more effective than BHT (butylated hydroxytoluene) in enhancing the quality parameters of the fermented sausage, suggesting the use of the plant in sausage industry to enhance its total quality (Bozkurt, 2006).

Nasar-Abbas and Halkman (2004) established that the level of inhibitory action exerted by the *R. coriaria* extract on the bacteria tested was analogous to that commonly used in food products, the concentration at which the plant extract exerts a desirable antibacterial effect may be higher in foods than that studied in vitro, but joined with other agents, it may help to control bacterial growth in foods. The antimicrobial properties of the plant on pathogenic bacteria in meat have also been evaluated (Radmehr and Abdolrahimzade, 2009). From the results, sumac exhibited significant antimicrobial effects on the total microbial and *Salmonella* count in minced meat for one week. The plant extract was found to be effective in stabilizing peanut oil compared with BHA, in which the antioxidant efficiency lasted for about 4 weeks. Curiously, the inhibition of autoxidation was proportional to the concentration, suggesting that high concentrations of sumac extract contribute mainly to the demonstrated antioxidant activity. Also, the data can support the application of *R. coriaria as* a natural antioxidant in oily foods (Özcan, 2003).

Waste extracts of *R. coriaria* are considered a potential source of natural, safe, plentiful, and also a cheap antimicrobial resource for food, acting as a surface decontaminant replacement by the use of the synthetic and chemical antimicrobials in the poultry industry, since it showed to be superior to lactic acid (antimicrobial preservative) in terms of the quality of poultry meats (Vatansever *et al.*, 2008). The activity of the plant extract might be due to the synergistic activity of slowing down the growth rate of contaminants, originated from both water soluble tannins and organic acids (Gulmez *et al.*, 2006).

However, the production of pure sumac extract powder by using a carrier (maltodextrin) through spray drying has been recently developed (Caliskan and Nur Dirim, 2013). This sumac powder mix can be effectively used in poultry and meat food production chains.

7. Conclusions

Since ancient times, *R. coriaria* has been used as an important seasoning spice, in medicine, as well as in the industry of leather. Different earlier studies suggest that this plant possesses varied therapeutic uses, including antioxidant, anti-inflammatory, antibacterial, antifungal, and hypoglycemic properties. These observed biological properties may be attributed to the presence of individual phytochemicals, mainly phenolic compounds. *R. coriaria* is thought to be very rich in these compounds.

Leaves and fruits of *R. coriaria* are recognized to have defensive and beneficial effects on numerous diseases, such as diabetes mellitus, some cancers, inflammation, dysentery, and digestive tract system ailments. Moreover, it possesses potential antiviral, antibacterial, antifungal, antioxidant and hypolipidemic activities.

In this review, we have explored the recent phytochemical and biological research available on this well-known plant. Therefore, a comprehensive account of its healing activity, both from a traditional and pharmacological point of view, is presented along with phytochemical components which are nutritionally and medicinally significant. From the present review, it can be concluded that the plant extracts possess compounds with antibacterial and antifungal potential that can be used to treat microbial infectious diseases, as well as in the food industry. The plant extracts can be used to search for bioactive natural products that help in the development of new drugs and food preservatives; it is also worthy to point out the important role of the plant in industry in view of many recent findings and its potential for future research.

The review also aimed at updating the current phytochemical, biological and medicinal knowledge available so far on *R. coriaria;* it also highlights the importance of *R. coriaria* extracts as a promising and potential source of functional ingredients and nutraceuticals with desirable bioactivities, urging further uses of sumac as a food preservative in pharmacology and functional food industries.

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