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Review

A Comprehensive Review of Phytochemistry and Biological Activities of *Quercus* Species

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Abstract: The *Quercus* genus provides a large amount of biomaterial with many applications in fields like pharmaceutics, cosmetics, and foodstuff areas. Due to the worldwide dissemination of the genus, many species were used for centuries in traditional healing methods or in the wine maturing process. This review aims to bring together the results about phytoconstituents from oak extracts and their biological applicability as antioxidants, antimicrobial, anticancer, etc. The literature data used in this paper were collected via PubMed, Scopus, and Science Direct (2010–June 2020). The inclusion criteria were papers published in English, with information about phytoconstituents from *Quercus* species (leaves, bark and seeds/acorns) and biological activities such as antioxidant, antibacterial, antiobesity, anti-acne vulgaris, antifungal, anticancer, antiviral, antileishmanial, antidiabetic, anti-inflammatory. The exclusion criteria were the research of other parts of the *Quercus* species (e.g., galls, wood, and twigs); lack of information about phytochemistry and biological activities; non-existent *Quercus* species reported by the authors. The most studied *Quercus* species, in terms of identified biomolecules and biological activity, are *Q. brantii*, *Q. infectoria* and *Q. robur.* The *Quercus* species have been reported to contain several phytoconstituents. The main bioactive phytochemicals are phenolic compounds, volatile organic compounds, sterols, aliphatic alcohols and fatty acids. The, *Quercus* species are intensely studied due to their antioxidant, anti-inflammatory, antimicrobial, and anticancer activities, provided by their phytochemical composition. The general conclusion is that oak extracts can be exploited for their biological activity and can be used in research fields, such as pharmaceutical, nutraceutical and medical.

Keywords: *Quercus*; oak; phenolic compounds; bark; acorn; antioxidant; antibacterial; antitumoral

1. Introduction

The *Quercus* genus is an evergreen or deciduous tree, belonging to the Fagaceae family. These genus contain about 450 species and represent an important tree group widespread in Europe, Asia, North Africa, North, Central and South America. The white oaks (section *Quercus*), live oaks (series Virentes) golden cup or intermediate oaks (section Protobalanus) and red oaks (section Lobatae) are present in America. The cycle cup oaks (subgenus Cyclobalanopsis) are found in Asia and the white oaks along with black oaks (section Cerris) are extended into Eurasia [1–3].

Quercus species are widespread in Northern Hemisphere, in temperate seasonally dry forests, and tend to be distributed in well-drained upland areas and often in montane areas and some species

are able to tolerate some degree of flooding (*Q. lyrata* and *Q. laurifolia*). The most common deciduous broad-leaved trees are *Q. ilex*, *Q. dentata*, *Q. acutisssima*, *Q. variabilis*, *Q. acuta*, *Q. glauca*, *Q. serrata* and *Q. salicina*. The most studied oaks are the European oaks, principally *Q. robur* (english oak) and *Q. petraea* (sessile oak or durmast oak) [4,5].

The *Quercus* species produce a universally known fruit (acorn) and, together with bark and leaves, has been used in traditional medicine, applied as antiseptic or in gastrointestinal disorders. Due to their nutritional role acorns are used as food for both humans and animals. The oak wood has important role in wine maturation in oak barrels and in the wood industry for the wood color, durability, and protection against fungal decay [1,6–8].

Large areas of oak forests (Europe, Asia, North Africa, North America, Central and South America), large amounts of forest waste (oak bark and leaves) resulting from wood processing, high availability and their drought resistance make *Quercus* species important sources of bioactive compounds. In the same time, the diversity of folk uses and the richness of phytochemicals found in *Quercus* species make this genus interesting for assessing biological activities and toxicological effects.

The aim of this review is to update the literature data (2010–June 2020) about phytochemistry and biological activities of *Quercus* species and to discuss their potential as antioxidants, antimicrobials, anti-inflammatories, and other activities.

2. Phytochemistry

The *Quercus* species have been reported to contain several phytoconstituents with significant differences between species due to the high variability. Even so, there are some classes of compounds that are ubiquitous in all *Quercus* species (Figure 1). The main bioactive phytochemicals are phenolic compounds, commonly found as glycosides [9]. Other compounds that can be found in *Quercus* species are volatile organic compounds, vitamins (especially vitamin E), sterols, aliphatic alcohols and fatty acids [9,10].

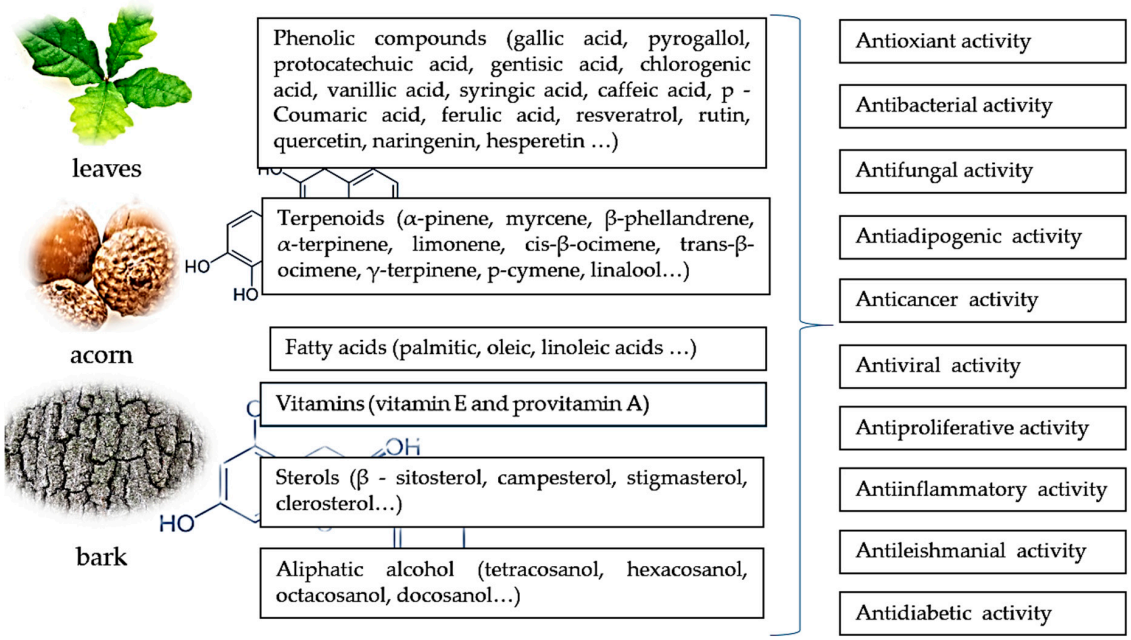

Figure 1. The main phytochemical compounds and biological activities of *Quercus* sp.

Phenolic compunds (Figure 2) are one of the largest groups of secondary metabolites in the plants with great importance due to their occurrence and the pharmacological properties [11]. These compounds show a large diversity of structures from simple molecules (e.g., phenolic acids) to polyphenols (e.g., stilbenes, flavonoids, and derived polymers) [12]. These compounds protect

the plants against some herbivores and affect positively mammals (humans included) due to the antioxidant, antimicrobial, anti-inflammatory and anticarcinogenic activities [13]. Even though, phenolic compounds display a large variety of biological activities, most of them are secondary effects of the antioxidant activity, which has several proposed mechanisms of actions. The general idea is that phenolic compounds may provide an electron to be donated or the whole hydrogen atom, from the O–H bond, to be transferred to free radical molecules, thus transforming the free radicals into harmless species. This process also transforms the phenolic into a radical, with an odd electron, but because of the aromatic structure the odd electron has the possibility to be spread over the entire molecule, resulting in a radical stabilization [14].

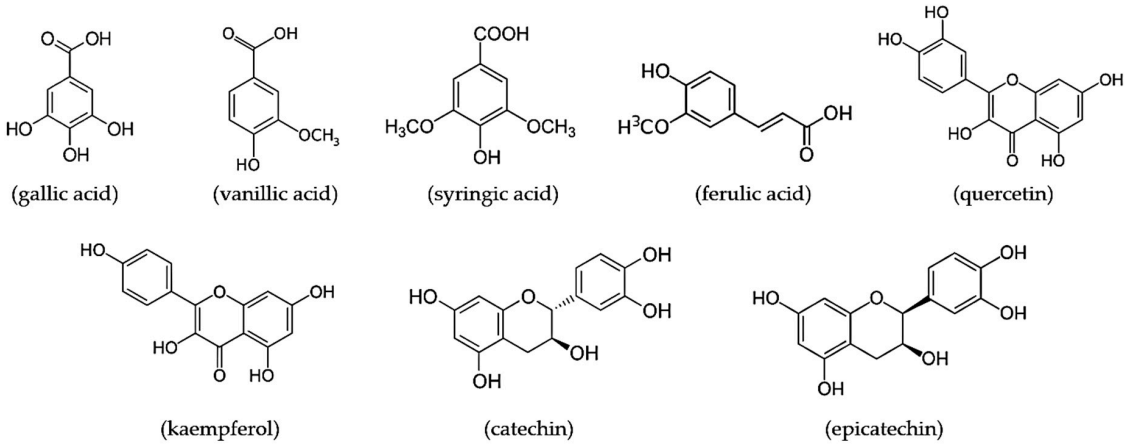

Figure 2. Chemical structures of the main phenolic compounds found in *Quercus* species.

The investigation of phenolic compounds *Quercus* species shows their presence in all organs (leaves, bark, and acorn). There is a complex variation in the production of individual phenolic compounds across *Quercus* species. Significant differences exist between absolute and relative concentration of polyphenols. For example, the ellagitannin production in white *Quercus* leaves may be characterized as products of castalagin and vescalagin [15], whereas in the black *Quercus* species these compounds are in relatively lower amounts without derivatives. These differences between oak phenolic compounds explain ecological differences between species [15].

The phenolic compounds identified in the *Quercus* species are mostly flavonoid and non-flavonoid phenolic constituents that intermediate the phenylpropanoid metabolism by shikimate pathway [16]. The resulting hydroxycinnamic acids and esters participate in reductase, oxygenase and transferase processes, resulting in a characteristic pattern of secondary metabolites for each plant species. For example, flavan-3-ols, flavonols and acylated kaempferol glucosides were identified and quantified in *Q. ilex* extracts [17]. Below, the main bioactive compounds present in the *Quercus* genus, at the level of bark, leaves and acorns, will be presented.

The main phenolic compounds identified in the leaves of *Quercus* species (Table 1) are phenolic acids (e.g., gallic acid, ellagic acid, protocatechuic acid, gentisic acid, chlorogenic acid, vanillic acid, syringic acid, caffeic acid, p-coumaric acid, and ferulic acid), flavonoids (e.g., rutin, quercetin, epicatechin, naringenin, hesperetin, formononetin, naringin, kaempferol) or tannins. These compounds are identified especially in the leaves of *Q. glauca*, *Q. incana*, *Q. ilex*, *Q. mongolica*, *Q. salicina*, *Q. petraea*, and *Q. robur* [18–20] with differences between the quantities of each compound. In the leaves of *Q. resinosa* the presence of epicatechin, vanilin, p-coumaric acid, benzoic acid, salicylic acid, syringic acid, gallic acid, p-hydroxybenzoic acid, catechin, vanillic acid, chlorogenic acid, 4-hydroxy-3-methoxybenzoic acid, and caffeic acid have been shown [21].

The *Quercus* bark can be considered a possible renewable source of bioactive compounds due to the large quantities of polyphenols. The main phenolic compounds identified in *Quercus* bark extracts (Table 1) are phenolic acids (e.g., caffeic acid, ellagic acid, gallic acid, and protocatechuic acid),

tannins (ellagitannins, roburins) and flavonoids. The *Quercus* species in which the phenolic profile of the bark extracts was analyzed are *Q. acutissima*, *Q. alba*, *Q. macrocarpa*, *Q. petraea*, *Q. robur* and *Q. sideroxyla* (Table 1). Hosam et al. [22] showed the presence in bark extracts of catechin, caffeic acid, ellagic acid, epicatechin, epigallocatechin, epigallocatechin gallate, gallic acid, and in *Q. acutissima*, the presence of caffeic acid, ellagic acid, epicatechin, epigallocatechin, gallic acid and protocatechuic acid in *Q. macrocarpa* and the presence of catechin, ellagic acid, gallic acid, protocatechuic acid and vanillic acid in *Q. robur* [22].

The *Quercus* species produce a widely known fruit, identified as an acorn [9]. Traditionally, acorns have been used in animal feed. The nutritional value and the high content in phytochemical compounds with biological activity led to the use of acorns in the human diet [23]. There are a considerable number of publications dedicated to phenolic compounds in acorns, which are integrated in the review of Vinha et al. [23]. The main phenolic compounds identified in *Quercus* acorns extracts are phenolic acids (gallic acid, ellagic acid, and their derivatives), flavonoids (quercetin, catechin, naringin) and tannins. These compounds have been identified in acorns of *Q. brantii*, *Q. floribunda*, *Q. glauca*, *Q. incana*, *Q. mongolica*, *Q. robur* (Table 1). Thus, it is reported that *Quercus* acorns had an important content of carbohydrates, amino acids, proteins, lipids, and various sterols [24]. The terpenoid metabolites are involved in plant growth and development but predominantly for more specialized chemical interactions and protection in the abiotic and biotic environment [25]. For example, terpenes like α-thujene, α-pinene, camphene, sabinene, α-pinene, myrcene, β-phellandrene, α-terpinene, limonene, cis-β-ocimene, trans-β-ocimene, γ-terpinene, p-cymene, linalool, 3-methyl-3-buten-1-ol, 3-methyl-3-buten-1-yl acetate were identified in *Q. ilex* leaves [26] while β-amyrin, betulinic acid, lupeol, betulin oleanolic acid, hederangenin, corosolic acid, arjunic acid, were found in the sapwood of *Q. faginea* [27]. A study published in 2009 [28] showed that *Q. robur* emits a high amount of isoprene, but also low amounts of α-pinene, camphene, myrcene, β-pinene, in some cases 1,8-cineol and limonene could also be identified. Welter et al. [29] showed *Q. canariensis* almost exclusively emitted isoprene, while *Q. suber* exclusively emitted monoterpenes (mainly α-pinene, β-pinene, sabinene, myrcene and limonene), occasionally β-ocimene was identified in the emissions of both species, while traces of α-thujene, camphene, α-terpinene, γ-terpinene and terpinolene were found only in *Q. suber* [29].

The *Quercus* genus may also contain other compounds, like fatty acids, for example, palmitic, oleic and linoleic acids being the most abundant fatty acids in the acorns (Table 1). The kernel oil obtained from *Q. robur* and *Q. cerris* also rich in these fatty acids, stearic, arachidic and α-linolenic acids being also present, but in smaller quantities [30].

Other studies have shown that acorns may also contain vitamins (vitamin E and provitamin A) [9]. Rabhi et al. [31] showed that *Q. ilex* and *Q. suber* oils contain 2 vitamers of vitamin E, those being α-tocopherol and γ-tocopherol, the second being present in a significantly higher concentration. The same study analysed the content of sterols and aliphatic alcohols in *Q. ilex* and *Q. suber*, the major sterol being β-sitosterol followed by lower amounts of campesterol, stigmasterol, clerosterol, Δ5-avenasterol, Δ5,24-stigmastadienol, Δ7-stigmastenol and Δ7-avenasterol [31]. Similar compounds were identified in the sapwood of *Q. faginea* the most abundant aliphatic alcohol being docosanol followed by tetracosanol, octadecanol, pentacosanol, hexacosanol and hexadecanol, while the most abundant sterol was β-sitosterol; campesterol, stigmasterol, stigmastanol, γ-sitostenone and stigmastane-3,6-dione could also be identified in the sapwood of this species [27].

3. Biological Activity of *Quercus* Extracts

The ethnobotanical data show that *Quercus* spp. can be valuable plants, especially for the treatment of gastrointestinal disorders, skin and urinary tract infections (e.g., *Q. ilex*, *Quercus oblongata* D. Don) [32,33]. The *Quercus* acorns are edible (animal feed or human diet), astringent and diuretic, used in diarrhea, indigestion and asthma [23]. The wood can be used for timber, fuel or in agricultural tools (handles of plough, axes, gun buts, and walking sticks) [34,35]. Starting from ethnobotanical

results, the researchers performed numerous experiments to demonstrate the biological activity of phytochemicals found in *Quercus* species.

3.1. Antioxidant Activity

Due to the biomolecules variety present in different parts of oaks, their power as an antioxidant and their beneficial aspects in multiple applications has been reported [36].

Some studies showed a highly and significant correlation between phenolic contents and antioxidant activity and that may be the reason for stronger radical scavenging activities [37]. Nedamani et al. [38] concluded that antioxidant activity showed by *Q. brantii* extract's reducing power is related to their total phenolic content, and Tuyen et al. [39] showed a strong correlation between phenolic content in *Q. mongolica* ssp. *crispula* leaves and bark extract and its antioxidant power. Many other studies showed the antioxidant effect of oak tannins in somatic cells beside other effects [40,41]. Kim et al. [42] reported that methanolic extract of *Q. acuta* showed the highest radical scavenging activity and total phenolic content, while the reducing power was the highest in the water extract. Along with the type of extract, it was showed that the radical scavenging activity was increased by increasing concentrations of *Q. brantii* leaf extract [43].

As to applicability, Ferreira et al. [44] revealed the protective effect of acorn extract of *Q. ilex* against oxidative degradation of lipids and proteins carbonylation. These effects are probably related to the intense antioxidant activity of polyphenols from acorns and so they may be used as preservatives in the alimentary industry, in nutraceutical and pharmacology activities. Another applicability of antioxidant power is noted by Horvathova et al. [45]. The *Q. robur* extract showed stimulation of antioxidant enzymes, decreasing damage to proteins and lipids, and a moderate increase in the total antioxidant capacity of plasma on human subjects. The authors concluded that the extract can be used as a natural supplement for improving the life quality in humans.

The most common antioxidant compounds in *Quercus* species are gallic and ellagic acid. Gallic acid (3,4,5-trihydroxybenzoic acidis) is a most popular phenolic compound, a natural antioxidant that is basically a secondary metabolite [46]. The ellagic acid is a polyphenol that occurs largely in woody eudicotyledons plants [47]. This phenolic acid is one of the highly investigated phytochemicals, with antioxidant, antimutagenic, and anticancer properties [48]. Thus, the antioxidant activity of *Quercus* extract can be attributed and to gallic and ellagic acid. Other common phenolic compounds from *Quercus* species are ellagitannins, including castalagin, vescalagin and roburin. It has been previously demonstrated that these compounds have potent antioxidant activity [49].

Table 1. The biological activities of natural extracts obtained by *Quercus* (Fagaceae) species.

Quercus Species: Scientific and Common Name	Raw Materials	Extract Type	Main Compounds Identified	Biological/Pharmacological Activities	References
Quercus acuta Thunb.—Japanese evergreen oak	Leaf	Hexane, Ethyl acetate, Acetone, Methanol, Ethanol, Water extract	Cinnamic acid, phytol, α-linolenic acid, α-tocopherol, β-sitosterol, β-amyrin, and friedelin-3-ol	- Antioxidant activity (methanolic extract showed the highest radical scavenging activity and total phenolic content, while the reducing power was the highest in the water extract); - Antibacterial activity against *Staphylococcus aureus*, *Salmonella typhimurium*, *Escherichia coli*, *Micrococcus luteus* and eight Meticilin Resistant *Staphylococcus aureus* (MRSA) and strains shown by ethyl acetate extract	[42]
	Leaf	Ethyl acetate extract	Vitamin E, loliolide, sesquiterpene (neophytadiene), triterpene (α-amyrin, friedelin) Phytosterol (stigmasterol), palmitic acid, linolenic acid, flavonoids (quercetin, luteolin, apigenin)	- Antioxidant activity; - Antihyperuricemic and xanthin oxidase inhibitory activity - Hyperuricemic mice demonstrated that leaf extract could inhibit hepatic xanthin oxidase activity and significantly alleviate hyperuricemia to a similar extent to allopurinol	[50]
Quercus acutissima Carruth.—sawtooth oak	Acorn shell	Water and methanol extract	Phenolic compounds	- Antioxidant activity; - Anti-adipogenic activity	[51]
	Acorn	Ethanol extract	-	- Antiobesity effect—quercus fruit extract attenuated increasing lipid dropplet size in retroperitoneal fat tissue and hepatic lipid accumulation induced by high-fat diet in mice	[52]
	Bark	Water axtract	Flavonoids, gallotannin, ellagitannin	- Anti acne vulgaris—inhibited androgen-related pathogenesys of acne, testosterone conversion, and sebum synthesis partially through inhibition of 5α-reductase activity and testosterone-induced sebum synthesis in rats	[53]
		Methanol extract	Phenolic acids (caffeic acid, ellagic acid, gallic acid, and protocate-chuic acid)	- Antibacterial activity against *Pseudomonas aeruginosa*, *Bacillus cereus*, *Listeria monocytogenes*, *Escherichia coli*, *Staphylococcus aureus*, *Mariniluteicoccus flavus;* - Antifungal activity against *Aspergillus flavus*, *Aspergillus ochraceus*, *Aspergillus niger*, *Candida albicans*, *Penicillum feniculosum*,*Penicillum ochrochloron;* - Anticancer activity against breast cancer cell line, cervical cancer cells, human T lymphocyte cells, human colon cancer cell line, human embryonic kidney cells	[22]

Table 1. *Cont.*

Quercus Species: Scientific and Common Name	Raw Materials	Extract Type	Main Compounds Identified	Biological/Pharmacological Activities	References
Quercus alba L.—white oak	Bark	Methanol extract	Ellagitannins, procyanidins, triterpenes	- Antibacterial activity against *Streptococcus aureus*, *Acinetobacter baumannii*, *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, *Acinetobacter baumannii*, *Staphylocccus epidermidis;* - Antibiofilm activity against *Staphylococcus aureus*	[54]
		Water extract	-	- Antibacterial activitity against *Staphylococcus aureus*	[55]
Quercus brantii Lindl.—Brant's oak	Acorn	Ethanol extract	Phenolic compounds	- Antiviral activity against Herpes Simplex Virus type 1 (HSV-1)	[56]
		Methanol extract	Phenolic compounds	- Antioxidant activity showed by extract's reducing power related to their total phenolic content	[38]
		Ethyle alcohol extract	Phenolic compounds	- Antiproliferative activity—crude ethyle alcohol extract and the n-butanol and chloroform fractions of *Q. brantii* supress the proliferation of cancer cells through induction of early apoptosis	[57]
		Ethanol extract	Phenolic compounds	- Antioxidant activity; - Antibacterial activity against *Staphylococcus aureus* and *Enterococcus faecalis*	[58]
		Powder and hydro-alcoholic extract	Phenolic compounds	- Antioxidant activity; - Anti-inflammatory activity	[59]
	Leaves	Alcoholic extract	Polysaccharide	- Antioxidant activity—the radical scavenging activity was increased by increasing concentration of leaf extract; - Antibacterial activity against *Salmonella typhi*, *Staphylococcus aureus;* - Antifungal activity against *Candida albicans*, *Planococcus citri*	[43]
	Acorn	Hydro-alcoholic extract	-	- Antifungal activity against vaginal cadidiasis; results of *the Q*, *brantii* extract vaginal douche are the same as the clotrimazole vaginal cream	[60]

Table 1. *Cont.*

***Quercus* Species: Scientific and Common Name**	**Raw Materials**	**Extract Type**	**Main Compounds Identified**	**Biological/Pharmacological Activities**	**References**
Quercus castaneifolia C.A. Mey—chestnut - leaved oak	Acorn	Methanol extract	-	- Anti-toxoplasma activity	[61]
Quercus cerris L.—Turkey oak, Austrian oak	Seed	Water extract	flavonoids, ellagic acid, gallotaninns, ellagitannins, α-tocopherol	- Antioxidant activity	[62]
	Leaves	Water extract	-	- Antibiofilm activity against *Staphylococcus aureus*	[63]
Quercus coccifera L.—kermes oak	Bark and lower stems	Methanol extract	Lignan (lyoniresinol), cocciferoside, chlorocatechin, polydatin	- α-glucosidase inhibitory activity; - Tyrosinase inhibitory activity	[64]
Quercus crassifolia Bonpl.—mexican oak	Bark	Ethanol and water extract	Polyphenols (flavonoids, hydroxycinnamic acids)	- Antioxidant activity	[65]
				- Antioxidant activity; - Antibacterial activity against *Escherichia coli;* - Toxic activity on kidney was observed associated with short-term repeated administration of *Q. crassifolia* bark extract in rats	[66]
Quercus mongolica ssp. *crispula* (Blume) Menitsky—mizunara	Leaves and bark	Ethanol extract	Ellagic acid, chlorogenic acid, benzoic acid	- Antioxidant activity—strong correlation between phenolic content in studied extract and its antioxidant power	[39]
	Leaves	80% acetone extract	-	- Potent anti-inflammatory activity; - Anti-Acne Vulgaris Effects	[67]
Quercus floribunda Lindl. Ex A. Camus	Acorn	Water, Methanol, N-Hexane, Chloroform extracts	Flavonoids, quercetin, gallic acid, catechin and chlorogenic acid, pyrocatechol	- Antioxidant activity; - Anticancer activity against human liver cancer cell line and monocytic leukemia cell line; - Antibacterial activity—mildly active against *Bacillus subtilis*, *Escherichia coli*, *Klebsiella pneumonie* and *Staphylococcus aureus;* - Antidiabetic activities—mild to moderate α-amylase inhibition; - Antileishmanial activity	[68]

Table 1. *Cont.*

Quercus Species: Scientific and Common Name	Raw Materials	Extract Type	Main Compounds Identified	Biological/Pharmacological Activities	References
Quercus gilva Blume—red-bark oak	Leaves and bark	Aqueous acetone extract	Cathechins, tannins	- Antioxidant activity; - Anti-urolithiasis effect	[69]
Quercus glauca Thunb.—ring cupped oak, Japanese blue oak,	Bark	Ethanolic extract	Lignans, lignanoids, triterpenoids, flavonoids	- Antioxidant activity	[70]
Quercus ilex L.—evergreen oak, holy oak	Acorn pulp	Acetone and water extract	Phenolic compounds	- Antioxidant activity	[44]
	Acorn	Water extract	Phenolic compounds	- Antidiarrheal activity	[71]
	Leaves	Hydro-methanol extract	Phenolic acids—(gallic, protocatechuic, ellagic acid derivatives, and ellagic acid), flavonoids, (catechin, epicatechins, and quercetin)	- Anti-inflammatory activity—extract decreased neutrophil infiltration and reduced the inflammatory citokines in ulcerative colitis rats	[72]
	Bark	Water and methanol extract	Flavonoids, catechins	- Antibacterial activity against *Streptococcus mutans*	[73]
Quercus incana Bartran—bluejack oak, cinnamon oak	Bark	Methanol extract	Flavonoids, tannins	- Antioxidant activity; - Antibacterial activity against *Bacillus subtilis*, *Streptococcus pyogenes*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Klebsiella pneumonie*, and *Escherichia coli;* - Antifungal activity against *Candida glabrata*, *Candida albicans*, *Aspergillus niger*, *Aspergillus flavus*, *Fusarium solani*, *Microsporus canis*	[74]
	Leaves	Chloroform, Methanol n-hexane extract	Flavonoids (eupatorin), triterpene (betulin)	- Anticancer activity—inhibition observed by betulin against large cells lung cancer was dose- and time-dependent; betulin has completely eradicated cancer cells even after 15 days of incubation in culture media during colony formation assay compared to the control	[75]
Quercus infectoria G. Olivier—aleppo oak	Acorn	Ethanolic exract	Phenolic compounds	- Anti-biofilm activity on MRSA and MSSA (Meticilin Susceptible *Staph. aureus*)	[76]
		Methanolic extract	Tannins, phenols and flavonoids	- Antioxidant activity - Antileichmanial active;ity against *Leichmania major*	[77]
		Ethanol and water extract	p-hydroxybenzoic acid, pyrogallol, catechol, caffeine, cathechine, e-vanillic, 3-hydroxythyro-sol, naringin, rutin	- Antibacterial activity against *Escherichia coli*, *Salmonella Typhimurium*, *Pseudomonas aeruginosa*, and *Staphylococcus aureus;* - – Antifungal activity—against *Candida albicans*	[78]

Table 1. *Cont.*

Quercus Species: Scientific and Common Name	Raw Materials	Extract Type	Main Compounds Identified	Biological/Pharmacological Activities	References
		Water extract	Tannins	- Antibacterial activity against MRSA through interference of various metabolism and function of the bacterial proteome	[79]
		Methanol extract	Alkaloids, flavonoids, steroids, tannins	- Analgesic activity	[80,81]
		Water extract	-	- Anti-inflammatory activity and non-toxic activity on acute and chronic administration in rats	[82]
	Bark	Acetone extract	Phenolic compounds	- Anti-quorum sensing activity—reduced the pyocyanin, protease, elastase production and biofilm formation in *Pseudomonas aeruginosa*	[83]
	Acorn	Hidroalcoholic axtract	-	- Antiangiogenic activity—the extract prevented the formation of endothelial tubular structures by endotelial cells, inhibited the ability of cellular migration and decreased the vascular endothelial growth factor secretion	[84]
		Acetone and methanol extract	-	- Antibacterial activity of acorn extract in combination with Vancomycin against two strains of MRSA. The time-kill curves showed a faster killing rate than Vancomycin alone and a synergic interaction	[85]
		Ethanol extract	-	- Antifungal activity against *Candida albicans* compared with fluconazole	[86]
		Aqueous extract	-	- Antibiofilm activity against *Pseudomonas aeruginosa*	[87]
		Ethanol extract	Phenolic acids (tannic acid, gallic acid, ellagic acid), flavonoids	- Anti-inflammatory activity—extract treatment ameliorated the inflammatory phenotype of bone marrow derived macrophages induced by prediabetic or diabetic environments	[88]
		Water extract	Gallic acid, syringic acid	- Antiosteoporothic—*Q. infectoria* semipurified fractions combined with osteoporotic drug pamidronate induce bone formation in human fetal osteoblast cell model, and increase the efficiency of pamidronate acting on osteoblast cell.	[89]

Table 1. *Cont.*

***Quercus* Species: Scientific and Common Name**	**Raw Materials**	**Extract Type**	**Main Compounds Identified**	**Biological/Pharmacological Activities**	**References**
Quercus laurina Bonpl.—mexican oak	Bark	Ethanolic and water extract	-	- Antioxidant activity	[65]
Quercus oblongata D. Don—banj oak	Bark	-	Mono-terpenoids (1,8–cineol, γ-terpinene), sesquiterpenoids, aliphatic aldehydes	- Antimicrobial activity and sinergic effect against *Streptococcus pyogenes*	[90]
	Acorn	-	Palmitic and stearic acids	- Antibacterial activity against *Bacillus subtilis*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Escherichia coli*	[91]
	Leaves	-	Carbohydrates, protein	- Nutritional support for sustaining the minimal level of production (milk,meat) and increased food intake, nutrient digestibility in winter time on cattlles	[92]
Quercus macrocarpa Michx.—bur oak	Bark	Methanol extract	Caffeic acid, ellagic acid, protocatechuic, gallic acid, epicatechin, epigallocatechin	- Antioxidant activity; - Antibacterial activity against *Pseudomonas aeruginosa*, *Bacillus cereus*, *Listeria monocytogenes*, *Escherichia coli*, *Staphylococcus aureus*, *Mariniluteicoccus flavus;* - Antifungal activity against *Aspergillus flavus*, *Aspergillus ochraceus*, *Aspergillus niger*, *Candida albicans*, *Penicillum feniculosum*, *Penicillum ochrochloron;* - Anticancer activity against breast cancer cell line, cervical cancer cells, human T lymphocyte cells, human colon cancer cell line, human embryonic kidney cells	[22]
Quercus mongolica Fisch. ex Ladeb.—Mongolian oak	Leaves	Acetone extract	Tannins, flavonoids	- Anti-inflammatory activities	[93]
	Leaves	Acetone extract	Catechin, epigallocatechin, quercetin, kaempferol, glucopyranoside	- Antioxidant activity	[94]
	Acorn (cups)	Ethanol extract	Ellagic acid, kaempferol	- Hypoglycemic activity. After 15 days of oral administration in alloxan-induced diabetic rats, fasting blood glucose levels, cholesterol and triglyceride levels were significantly decreased; - Antioxidant activity; - Superoxide dismutase activity in heart, liver, spleen and kidney were significantly improved	[95]

Table 1. *Cont.*

***Quercus* Species: Scientific and Common Name**	**Raw Materials**	**Extract Type**	**Main Compounds Identified**		**Biological/Pharmacological Activities**	**References**
Quercus petraea (Matt.) Liebl.—sessile oak	Twigs, leaves, acorn	Water extract	Catechin, tannins, flavonoids, proanthocyanidin	-	Antioxidant activity	[1]
	Bark	Alcohol extract	Tannins (vescalagin, castalagin, grandinin and roburin E)	-	Antioxidant and antiinflammatory activity	[96]
Quercus phillyreoides A.Gray—ubame oak	Bark	Water extract	Alkaloids, flavonoids, saponins, tannins, terpenoids, antraquinone	-	Antifungal activity against *Lasiodiplodia theobromae*, *Aspergillus niger*, *Sclerotium rolfsii*, *Penicillum oxalicum*, *Rhizoctonia solani*, *Fusarium oxysporum*	[97]
Quercus pyrenaica Wild.—Pyrenean oak	Bark	Water/acetone and methanol extract	Vescalagin, castalagin, granidin and roburin E	-	nutraceutical and cosmetic applications	[98]
Quercus robur L.—common oak/pedunculate oak/European oak/English oak	Bark	Water extract	Gallic acid, ellagic acid, castalin/Vescalin granidinin/roburin E	-	Antioxidant activity	[99]
			Tannins (roburins)	-	Improvement in energy, tiredness and tension level associated with reduction of oxidative stress	[100]
			Phloroglucinol dihydrate, 4-propylresorcinol, pyrogallol	- -	Antibacterial activity against *Chromobacterium violaceum* Anti-quorum sensing effect agains *C. violaceum*	[101]
	Twigs, leaves and acorn	Water extract	Carotenoids, proanthocyanidin, tannins, flavonoids	-	Antioxidant activity	[1]
	Bark	Water extract	-	-	Antioxidant activity	[102]
			Roburins	-	Antioxidant activity	[45]
			Ellagitaninns	-	Antiinflammatory activity	[103]
			Ellagic acid	-	Antioxidant activity	[104]
	Acorn	-	-	-	Antioxidant activity	[105]
	Bark	Water extract	vanillin, coniferaldehyde, acetovanillone and syringaldehyde	-	Flavouring activity of grapewine	[106]

Table 1. *Cont.*

Quercus Species: Scientific and Common Name	Raw Materials	Extract Type	Main Compounds Identified	Biological/Pharmacological Activities	References
		Methanol extract	Alkaloids, anthraquinones, saponins, tannins and terpenoids	- Antioxidant activity; - Antibacterial activity against *Escherichia coli*, *Staphylococcus aureus*, *Klebsiella pneumoniae*, *Staphylococcus epidermidis* and *Bacillus subtilis*	[107]
			Ellagic acid, gallic acid, protocatechuic acid and vanillic acid	- Antioxidant activity; - Antibacterial activity against *Pseudomonas aeruginosa*, *Bacillus cereus*, *Listeria monocytogenes*, *Escherichia coli*, *Staphylococcus aureus*, *Mariniluteicoccus flavus;* - Antifungal activity against *Aspergillus flavus*, *Aspergillus ochraceus*, *Aspergillus niger*, *Candida albicans*, *Penicillum feniculosum*, *Penicillum ochrochloron;* - Anticancer activity against breast cancer cell line, cervical cancer cells, human T lymphocyte cells, human colon cancer cell line, human embryonic kidney cells and human urinary bladder cancer cells	[22]
		-	-	- Production of styrene by cultivating a fungus (*Penicillium expansum*) on forest waste biomass (oak bark) as a feeding substrate along with potato dextrose and yeast extract	[108]
		-	-	- Supplementation of diets in dairy cows with *Q. robur* extract reduced urinary N excretion and increased the concentration of α-linoleic acid in milk	[109]
	Acorn	Methanol/water extract	Phenolic compounds	- inhibitory effect on α-synuclein fibrillation, protein that its fibrillation is the causative factor of Parkinson's disease	[110]
	Bark	Ethanol extract	Gallic acid, castalagin, vescalagin, granidin, roburin E	- Antidiabetic activity determined by α- glucosidase inhibition assay	[111]
Quercus salicina Blume	Leaves and bark	Ethanol extract	Gallic and vanillic acids, flavonoids	- Antioxidant activity	[39]
				- Vasodilatator effect on porcine endothelium coronary artery	[112]

Table 1. *Cont.*

***Quercus* Species: Scientific and Common Name**	**Raw Materials**	**Extract Type**	**Main Compounds Identified**	**Biological/Pharmacological Activities**	**References**
Quercus scytophylla Liebm.—mexican oak	Bark	Ethanolic and water extract	-	- – - Antioxidant activity	[65]
Quercus serrata Murray—jolcham oak	Leaves and bark	Ethanol extract	syringic acid, cinnamic acids, flavonoids	- Antioxidat activity	[39]
	Seeds	Ethanol extract	Triterpenoid comounds fractions	- Anti-neuroinflammatory activity	[113]
Quercus sideroxyla Bonpl.	Bark	Ethanol extract	Gallic acid, catechin, epicatechin, gallocatechin, dimeric procyanidins	- Antihiperglycemic activity—mantaining the glucose levels to more stable levels by inhibiting the α-amylase enzyme	[114,115]
	Bark	Aqueous acetone extract	Gallic acid, catechin, epicatechin, gallocatechin, procyanidins, proanthocyanidins	- Antioxidant activity	[114]
Quercus suber L.—cork oak	Bark	Hidroalcoholic extract	Gallic acid, ellagic acid, vescalagin, castalagin, B-*O*-ethylvescalagin	- Antioxidant activity	[116]
		Acetone extract	Phenolic acids, proanthocianidins,	- Antifungal activity against *Trichophyton verrucosum*, *Trichophyton mentagrophytes*	[37]
		water extract	-	- Antibacterial activity against *Staphylococcus aureus*, *Escherichia coli*	[117]
Quercus variabilis Blume—Chinese cork oak	Acorn cups and shell	Ethanol and water extract	Ellagic acid, tannins	- Antioxidant activity; - Antibacterial activity against *Staphylococcus aureus*, *Salmonella parathyphi*, *Salmonella thyphimurium*, *Salmonella enteritidis*, *Listeria monocytogenes*	[118]

3.2. Antibacterial and Antifungal Activity

Since ancient times, the traditional use of oak bark in medicine field was well known and applied topically to burns and wounds to prevent infection, or applied orally for gastrointestinal diseases. The *Quercus* extract (especially bark extract) contains important antimicrobial compounds such as gallic acid, ellagic acid, vescalagin or castalagin [119,120]. Due to its history of antibacterial uses, Deryabin and Tolmacheva [101] used *Q. robur* cortex against *Chromobacterium violaceum*. The results showed an anti-quorum sensing effect determined by the extract's bioactivity.

The antimicrobial activity is sustained by diverse results of experiments reported against *Streptococcus aureus*, *Acinetobacter baumannii*, *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*. Thus, *Q. alba* bark extracts inhibited growth in the strains of *Acinetobacter baumannii* and growth of *Staphylocccus epidermidis* and showed antibiofilm activity against *Staphylococcus aureus* [54]. Not only the oak bark but the leaves of *Q. brantii* have antibacterial and antifungal activity, as shown by Tahmouzi [43]. Acorn extract of *Q. brantii* showed antifungal activity against vaginal candidiasis [60] and *Q. floribunda* acorn extract showed mildly antibacterial activity against *Bacillus subtilis*, *Escherichia coli*, *Klebsiella pneumonie* and *Staphylococcus aureus*.

The antibacterial and antifungal activity can be the result of extract type, harvesting time, oak tree species, and the instrument quality and measurement methods. Tayel et al. [86] showed the antifungal activity against *Candida albicans* of the *Q. infectoria* acorn ethanolic extract. The acorns are concentrated in tannins (ellagitannins) more than other parts of oak trees and the antibacterial and antifungal activity can be attributed to these compounds [76]. Tannins have been shown to inhibit growth in a wide range of bacteria, fungi and viruses, inactivating the microbial enzymes, sequestering essential metal ions in complexes and inhibition of membrane transport [121]. Zhou et al. [118] showed antibacterial activity of *Q, variabilis* acorn extract, destroying the bacteria's wall cell and inhibits their normal growth and cellular metabolism. Khairon et al. [79] showed the antibacterial activity against MRSA of *Q, infectoria* acorn water extract through the interference of various metabolisms and functions of the bacterial proteome. Tannins also act as biofilm inhibitors by binding to matrix proteins [122]. Chusri et al. [76] highlighted the anti-biofilm activity on MRSA and MSSA due to *Q. infectoria* extract effect on *Staphilococcus aureus* cell wall and cell surface hydrophobicity.

Another use of oak extracts is in the cosmetic and pharmaceuticals industries [90], or in alimentary industry. The *Quercus* extract can be applied as a natural disinfectant and decontaminant for chicken eggs or for helping farmers to avoid fungicides due to their human and environmental hazards [97].

3.3. Anti-Inflammatory and Anticancer Activity

Along the time, more anticancer treatment were developed, but recently the evolving of cancer resistancy and side effects of the chemoterapic therapy, demands new chemicals with high potency, low side effects, and high selectivity at molecular level [75].

The *Quercus* genus is intensely studied due to its high potency against inflammation and proliferation of cancer cells. The main anticancer compounds identified in *Quercus* species are ellagic acid, kaempferol and its glycosides, quercetin, myricetin [123–126]. Farhad et al. [57] describe antiproliferative activity of *Q. brantii* crude extract that suppresses the proliferation of cancer cells through induction of early apoptosis as mechanism. The betulin compound found in *Q. incana* leaves extract by Hasan et al. [75] has completely eradicated large cells' lung cancer even after 15 days of incubation in culture media during colony formation assay compared to the control. Different cancer cells as MCF-7 (breast cancer cell line), HeLa (cervical cancer cells), Jurkat (human T lymphocyte cells), HT-29 (human colon cancer cell line), HEK 293 (human embryonic kidney cells) and T24 (human urinary bladder cancer cells) were tested by Elansary et al. [22] with great regression done by *Q. macrocarpa* and *Q. robur* bark extracts.

There are several studies showing anti-inflammatory activity. Castejón Martínez et al. [72] describe that phenolic extracts from *Q. ilex* leaves decreased neutrophil infiltration and reduced the inflammatory citokines in TNBS-induced ulcerative colitis rats. Chokpaisarn et al. [88] have described the *Q. infectoria*

acorn extract amelioration of inflammatory phenotype of bone marrow-derived macrophages induced by prediabetic or diabetic environments, potentially by inhibiting the Set-7/NF-κB pathway.

The phenolic compounds (e.g., ellagic acid) improves anti-inflammation through isolated compounds from *Q. mongolica* bark extract which showed inhibitory activities towards inflammatory cytokines and chemokines induced in ultraviolet B (UVB)-irradiated keratinocites by increasing the cell migration ability of cells and enhancing their regeneration when exposed to UVB, and these compounds can be further developed for treating the chronic inflammatory skin diseases, like atopic dermatitis and psoriasis [127].

3.4. Antidiabetic Activity

Diabetes mellitus is a metabolic disorder distinguished by a failure of glucose homeostasis with disturbances of carbohydrate, fat and protein metabolism as a result of defects in insulin secretion [128]. Phloridzin is a dihydrochalcone glycoside detected at higher concentrations in *Quercus* leaves, (e.g., *Q. resino*) [129]. This compound is recognized for its astringent properties and antidiabetic effects [129]. For example, an effect of *Q. coccifera* bark extracts is inhibition of α-glucosidase. This effect could be important in the treatment of diabetus mellitus, as Sari et al. [64] and Muccilli et al. [111] concluded. The other antidiabetic phenolic compounds from *Quercus* species can be ellagic acid, rutin or vescalagin [127,130,131]. The *Q. floribunda* acorn extract has mild to moderate α-amylase inhibition and this strategy is an essential target to manage blood glucose level in noninsulin dependent diabetes mellitus, as found by Soto et al. [115]. Another way to treat diabetes is observed after 15 days of oral administration of *Q. mongolica* acorn extract in alloxan-induced diabetic rats by Yin et al. [95]. They reported a hypoglycemic activity, but also the fasting blood glucose, cholesterol and triglyceride levels were significantly decreased.

Thus, the significant antidiabetic effect of the *Quercus* phenolic compounds could be due to the presence of the phenolic compounds, which could act synergistically or independently to enhance the activity of glycolytic enzymes.

3.5. Other Activities

Wine taste is clearly defined by the infusion of phytochemical components found in *Quercus* species such as *Q. petraea,* by Sindt et al. [132], who determined that the taste of three compounds extracted from oak bark, that were described for their bitterness and their influence in wine and brandy, increased in bitterness during oak aging. Jiménez-Moreno et al. [106] exhibit more clearly that the wine flavor which was in contact with oak bark displayed a more intense wood and spicy aroma, and more body and persistence in the mouth than the control wine, obtained after applying the toasted oak extract of *Q. robur*.

Antileishmanial activity against *Leishmania tropica* by *Q. floribunda* was studied with interest by Kheirandish et al. [77] who found that promastigotes treated with oak extracts were able to infect only 33.2% of the peritoneal macrophages and their infectiveness reduction was 51.3%. After 4 weeks of *Q. infectoria* acorn extract treatment, a decrease in the number of parasites compared to the control group was observed. Daryani et al. [61] showed anti-toxoplasma activity of *Q. castaneifolia* acorn methanolic extract by increasing the survival rate of the mice compared to the mice in the untreated infected control.

Antiadipogenesis is crucial for the prevention of obesity because adipogenesis occurs progressively throughout human life [133]. The antiadipogenic activity was revealed by *Q. acutissima* acorn extract, which decreased the intracellular lipid droplets in fat tissue and hepatic lipid accumulation and downregulates the diglyceride acyltransferase 2 gene expression as found by Youn et al. [51] and Hwang et al. [52]. The Youn et al. [51] speculated that inhibitory activities of aqueous/methanolic *Q. acutissima* acorn extracts and particularly the gallic acid, is mediated by regulation of the cell cycle and insulin signaling in the early stage of adipogenesis. Therefore, further study regarding the precise mechanism for the anti-adipogenic activity of acorn shell extracts is required.

Antiacne activity was found by Koseki et al. [53], which explained that *Q. acutissima* bark extract inhibited androgen-related pathogenesis of acne through inhibition of α-reductase activity in testosterone-induced sebum synthesis in rats.

Q. brantii acorn ethanol extract showed antiviral activity against HSV-1 (Herpes Simplex Virus type 1) by modulating the replication mechanism as suggested by Karimi et al. [56].

One of the interesting effects is shown by *Q. salicina* leaves and bark extract as the vasodilatator effect on porcine endothelium coronary artery, experienced by Park et al. [112]. *Q. gilva* leaves and bark extract inhibits the development of urolithiasis in the animal models, as described by Youn et al. [69], and *Q. infectoria* can be used as analgesic for mild pain relief [79] or for its antiosteoporothic activity, shown by Abdullah et al. [89].

The nutritional role is reminded by Paswan and Sahoo [92] for sustaining the minimal level of production (milk, meat) in wintertime by using *Quercus oblongata* leaves' extract.

Finally we have some reports regarding the toxicity of obtained extracts. The *Q. infectoria* acorn water extract showed non-toxic activity on acute and chronic administration in rats and no significant adverse effects [82]. One the other hand, the *Q. crassifolia* bark water extract appears to have toxic activity on kidney and was associated with short-term repeated administration in rats, as Valencia et al. [65] discovered.

4. Conclusions and Future Directions

This review unified results about biological activities of *Quercus* extracts and its isolated compounds. Most bioactivity studies were focused on antioxidant, antimicrobial and anticancer effects. Thus, the *Quercus* extracts are a great source of phytoconstituents, especially polyphenols. The general conclusion of scientists is that these extracts can be exploited for their antioxidants, antimicrobial and anticancer potential activities and can be used in diverse research fields, such as pharmaceutical, nutraceutical, medical, and for improving the wine sensory quality. Most of the pharmacological effects of *Quercus* genus can be explained by the high amount of phenolic compounds' content, especially tannins and their antioxidant potential. The pharmacological studies have mostly been performed in vitro and in vivo, and clinical studies are very limited. Thus, clinical studies are needed to confirm in vitro and in vivo results for a rational use in phytotherapy. These studies should be continuously developing newer techniques for treating multidrug resistance and quorum sensing activity as a bacterial biofilm formation. New anticancer therapies should be continuously developed because of the tendency of resistance to classical treatments. That is why more studies should concentrate on in vivo experiments. More studies are needed to show the link between the chemical compound and bioactivity and to discuss their action mechanism. Even if *Quercus* products are generally safe, more toxicological data are needed.

Large areas of oak forests, large amounts of forest waste (oak bark and leaves) resulting from wood processing, high availability and their drought resistance make *Quercus* species important sources of bioactive compounds.

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References

1. Popovic, B.; Stajner, D.; Ždero Pavlović, R.; Orlović, S.; Galić, Z. Antioxidant characterization of oak extracts combining spectrophotometric assays and chemometrics. *Sci. World J.* **2013**, *2013*. [CrossRef] [PubMed]
2. Nixon, K. Global and neotropical distribition and diversity of oak (Genus *Quercus*) and oak forests. In *Ecology and Conservation of Neotropical Montane Oak Forests (Ecological Studies)*; Springer: Berlin/Heidelberg, Germany, 2006; pp. 3–13.
3. Aldrich, P.R.; Cavender-Bares, J. Quercus. In *Wild Crop Relatives: Genomic and Breeding Resources*; Springer: Berlin/Heidelberg, Germany, 2011; pp. 89–129.
4. Box, E.O.; Fujiwara, K. Warm-temperate deciduous forests: Concept and global overview. In *Warm-Temperate Deciduous Forests around the Northern Hemisphere*; Springer: Cham, Switzerland, 2015; pp. 7–26.
5. Tanouchi, H.; Sato, T.; Takeshita, K. Comparative studies on acorn and seedling dynamics of four *Quercus* species in an evergreen broad-leaved forest. *J. Plant Res.* **1994**, *107*, 153–159. [CrossRef]
6. Council of Europe. *European Pharmacopoeia*, 7th ed.; Council of Europe: Strasbourg, France, 2011; Volume Supplement 1.
7. Martins, J.; de Oliveira, L.S.; Nisgoski, S.; Sabourin, R. A database for automatic classification of forest species. *Mach. Vis. Appl.* **2012**, *24*. [CrossRef]
8. Karioti, A.; Bilia, A.; Skaltsa, H. *Quercus ilex* L.: A rich source of polyacylated flavonoid glucosides. *Planta Med.* **2009**, *75*. [CrossRef]
9. Vinha, A.; Barreira, J.; Costa, A.; Oliveira, M. A new age for *Quercus* spp. Fruits: Review on nutritional and phytochemical composition and related biological activities of acorns. *Compr. Rev. Food Sci. Food Saf.* **2016**, *15*. [CrossRef]
10. Laemke, J.; Unsicker, S. Phytochemical variation in treetops: Causes and consequences for tree-insect herbivore interactions. *Oecologia* **2018**, *187*. [CrossRef]
11. Tanase, C.; Cosarca, S.; Muntean, D.-L. A critical review of phenolic compounds extracted from the bark of woody vascular plants and their potential biological activity. *Molecules* **2019**, *24*, 1182. [CrossRef]
12. Cheynier, V. Phenolic compounds: From plants to foods. *Phytochem. Rev.* **2012**, *11*. [CrossRef]
13. Engström, M. *Understanding the Bioactivity of Plant Tannins: Developments in Analysis Methods and Structure-Activity Studies*; Painosalama Oy: Turku, Finland, 2016.
14. Leopoldini, M.; Russo, N.; Toscano, M. The molecular basis of working mechanism of natural polyphenolic antioxidants. *Food Chem.* **2011**, *125*, 288–306. [CrossRef]
15. Yarnes, C.; Boecklen, W.; Tuominen, K.; Salminen, J.-P. Defining phytochemical phenotypes: Size and shape analysis of phenolic compounds in white oaks (Fagaceae, *Quercus Sect. Quercus*) of the Chihuahuan Desert. *Can. J. Bot.* **2006**, *84*. [CrossRef]
16. Vogt, T. Phenylpropanoid biosynthesis. *Mol. Plant* **2010**, *3*, 2–20. [CrossRef] [PubMed]
17. Hadidi, L.; Babou, L.; Zaidi, F.; Valentão, P.; Andrade, P.B.; Grosso, C. *Quercus ilex* L.: How season, plant organ and extraction procedure can influence chemistry and bioactivities. *Chem. Biodivers.* **2017**, *14*, e1600187. [CrossRef]
18. Cantos-Villar, E.; Espín, J.C.; Lopez, C.; Hoz, L.; Ordónez, J.; Tomás-Barberán, F. Phenolic compounds and fatty acids from acorns (*Quercus* spp.), the main dietary constituent of free-ranged iberian pigs. *J. Agric. Food Chem.* **2003**, *51*, 6248–6255. [CrossRef]
19. Jong, J.; Bimal, K.; Hyeun, C.; Kyung, J.; Ki, S.; Young, S.; Taek, S.; Ji, L.; Hye, K.; Min, C. Comparison of phenolic compounds content in indeciduous *Quercus* species. *J. Med. Plants Res.* **2012**, *6*, 5228–5239. [CrossRef]
20. Brossa, R.; Casals, I.; Pintó-Marijuan, M.; Fleck, I. Leaf flavonoid content in *Quercus ilex* L. resprouts and its seasonal variation. *Trees* **2009**, *23*, 401–408. [CrossRef]
21. Rocha-Guzmán, N.E.; Gallegos-Infante, J.A.; González-Laredo, R.F.; Reynoso-Camacho, R.; Ramos-Gómez, M.; Garcia-Gasca, T.; Rodríguez-Muñoz, M.E.; Guzmán-Maldonado, S.H.; Medina-Torres, L.; Lujan-García, B.A. Antioxidant activity and genotoxic effect on hela cells of phenolic compounds from infusions of *Quercus resinosa* leaves. *Food Chem.* **2009**, *115*, 1320–1325. [CrossRef]
22. Elansary, H.O.; Szopa, A.; Kubica, P.; Ekiert, H.; Mattar, M.A.; Al-Yafrasi, M.A.; El-Ansary, D.O.; Zin Elabadin, T.K.; Yessoufou, K. Polyphenol profile and pharmaceutical potential of *Quercus* spp. bark extracts. *Plants* **2019**, *8*, 486. [CrossRef]

23. Vinha, A.; Barreira, J.; Ferreira, I.; Oliveira, M. Therapeutic, phytochemistry, and pharmacology of acorns (*Quercus* nuts): A review. In *Bioactive Compounds in Underutilized Fruits and Nuts*; Springer: Cham, Switzerland, 2020; pp. 1–15. [CrossRef]
24. Lopes, I.; Bernardo-Gil, G. Characterisation of acorn oils extracted by hexane and by supercritical carbon dioxide. *Eur. J. Lipid Sci. Technol.* **2005**, *107*, 12–19. [CrossRef]
25. Tholl, D. Biosynthesis and biological functions of terpenoids in plants. *Adv. Biochem. Eng. Biotechnol.* **2015**, *148*. [CrossRef]
26. Loreto, F.; Ciccioli, P.; Brancaleoni, E.; Cecinato, A.; Frattoni, M.; Sharkey, T. Different sources of reduced carbon contribute to form three classes of terpenoid emitted by *Quercus ilex* L. leaves. *Proc. Natl. Acad. Sci. USA* **1996**, *93*, 9966–9969. [CrossRef]
27. Miranda, I.; Sousa, V.; Ferreira, J.; Pereira, H. Chemical characterization and extractives composition of heartwood and sapwood from *Quercus faginea*. *PLoS ONE* **2017**, *12*. [CrossRef] [PubMed]
28. Pérez-Rial, D.; Penuelas, J.; López-Mahía, P.; Llusia, J. Terpenoid emissions from *Quercus robur*. A case study of Galicia (NW Spain). *J. Environ. Monit.* **2009**, *11*, 1268–1275. [CrossRef] [PubMed]
29. Welter, S.; Bracho-Nuñez, A.; Mir, C.; Zimmer, I.; Kesselmeier, J.; Lumaret, R.; Schnitzler, J.-P.; Staudt, M. The diversification of terpene emissions in mediterranean oaks: Lessons from a study of *Quercus suber, Quercus canariensis* and its hybrid *Quercus afares*. *Tree Physiol.* **2012**, *32*, 1082–1091. [CrossRef] [PubMed]
30. Petrovic, S.; Sobajic, S.; Rakic, S.; Tomic, A.; Kukic, J. Investigation of kernel oils of *Quercus robur* and *Quercus cerris*. *Chem. Nat. Compd.* **2004**, *40*, 420–422. [CrossRef]
31. Rabhi, F.; Narváez-Rivas, M.; Tlili, N.; Boukhchina, S.; León-Camacho, M. Sterol, aliphatic alcohol and tocopherol contents of *Quercus ilex* and *Quercus suber* from different regions. *Ind. Crops Prod.* **2016**, *83*, 781–786. [CrossRef]
32. Meziti, H.; Bouriche, H.; Kada, S.; Demirtas, I.; Kizil, M.; Senator, A.; Garrido, G. Phytochemical analysis, and antioxidant, anti-hemolytic and genoprotective effects of *Quercus ilex* L. and *Pinus halepensis* mill. Methanolic extracts. *J. Pharm. Pharmacogn. Res.* **2019**, *7*, 260–272.
33. Joshi, A.K.; Juyal, D.S. Traditional and ethnobotanical uses of *Quercus Leucotrichophora* A. Camus (*Quercus oblongata* D. Don) in Kumaun and Garhwal regions of Uttarakhand, India: A review. *Int. J. Herb. Med.* **2017**, *5*, 06–08.
34. Jazib, M.J.; Rather, S.A. An ethno-botanical overview of oak: A multipurpose wild tree species of the Pir Panjal Himalayas. *Forest Res.* **2015**. [CrossRef]
35. Hamayun, M. Ethnobotanical studies of some useful shrubs and trees of district buner, NWFP, Pakistan. *Ethnobot. Leafl.* **2003**, *2003*, 12.
36. Singh, R.; Kumari, N. Comparative determination of phytochemicals and antioxidant activity from leaf and fruit of Sapindus Mukorrossi Gaertn.—A valuable medicinal tree. *Ind. Crops Prod.* **2015**, *73*. [CrossRef]
37. Akroum, S. Antifungal activity of acetone extracts from *Punica granatum* L., *Quercus suber* L. and *Vicia faba* L. *J. Mycol. Médicale J. Med. Mycol.* **2016**, *27*. [CrossRef] [PubMed]
38. Nedamani, E.R.; Sadeghi, A.; Ghorbani, M.; Kashaninejad, M. Evaluation of antioxidant interactions in combined extracts of green tea *(Camellia Sinensis)*, rosemary *(Rosmarinus Officinalis)* and oak fruit *(Quercus Branti)*. *J. Food Sci. Technol.* **2015**. [CrossRef]
39. Tuyen, P.T.; Khang, D.T.; Ha, P.T.; Hai, T.N.; Elzaawely, A.A.; Xuan, T.D. Antioxidant capacity and phenolic contents of three *Quercus* species. *Int. Lett. Nat. Sci.* **2016**, *54*, 85–99. [CrossRef]
40. Koleckar, V.; Kubikova, K.; Rehakova, Z.; Kuca, K.; Jun, D.; Jahodár, L.; Opletal, L. Condensed and hydrolysable tannins as antioxidants influencing the health. *Mini Rev. Med. Chem.* **2008**, *8*, 436–447. [CrossRef]
41. Takuo, O.; Hideyuki, I. Tannins of constant structure in medicinal and food plants - hydrolyzable tannins and polyphenols related to tannins. *Molecules* **2011**, *16*, 2191–2217. [CrossRef]
42. Kim, M.-H.; Park, D.-H.; Bae, M.-S.; Song, S.-H.; Seo, H.-J.; Han, D.-G.; Oh, D.-S.; Jung, S.-T.; Cho, Y.-C.; Park, K.-M.; et al. Analysis of the active constituents and evaluation of the biological effects of *Quercus acuta* Thunb. (Fagaceae) extracts. *Molecules* **2018**, *23*, 1772. [CrossRef]
43. Tahmouzi, S. Optimization of polysaccharides from zagros oak leaf using RSM: Antioxidant and antimicrobial activities. *Carbohydr. Polym.* **2014**, *106*, 238–246. [CrossRef] [PubMed]
44. Ferreira, V.; Morcuende, D.; Hérnandez-López, S.; Madruga, M.; Silva, F.; Estévez, M. Antioxidant extracts from acorns (*Quercus ilex* L.) effectively Protect Ready-to-Eat (RTE) chicken patties irrespective of packaging atmosphere: Acorn as antioxidant in convenience food. *J. Food Sci.* **2017**, *82*. [CrossRef] [PubMed]

45. Horvathova, M.; Országhová, Z.; Laubertova, L.; Vaváková, M.; Sabaka, P.; Rohdewald, P.; Durackova, Z.; Muchová, J. Effect of the french oak wood extract robuvit on markers of oxidative stress and activity of antioxidant enzymes in healthy volunteers: A pilot study. *Oxid. Med. Cell. Longev.* **2014**, *2014*, 639868. [CrossRef]
46. Watson, R.R.; Preedy, V.R.; Zibadi, S. Index. In *Polyphenols in Human Health and Disease*; Academic Press: San Diego, CA, USA, 2014; pp. 1401–1419. [CrossRef]
47. Girish, C.; Pradhan, S.C. Herbal Drugs on the Liver. In *Liver Pathophysiology: Therapies and Antioxidants*; Muriel, P., Ed.; Academic Press: Boston, MA, USA, 2017; pp. 605–620. [CrossRef]
48. Watson, R.R.; Preedy, V.R.; Zibadi, S. (Eds.) *Polyphenols: Mechanisms of Action in Human Health and Disease*, 2nd ed.; Academic Press: Cambridge, MA, USA, 2018. [CrossRef]
49. Chiarini, A.; Micucci, M.; Malaguti, M.; Budriesi, R.; Ioan, P.; Lenzi, M.; Fimognari, C.; Toschi, T.G.; Comandini, P.; Hrelia, S. Sweet chestnut (*Castanea sativa* Mill.) bark extract: Cardiovascular activity and myocyte protection against oxidative damage. *Oxid. Med. Cell. Longev.* **2013**, *2013*, 471790. [CrossRef]
50. Yoon, I.-S.; Park, D.-H.; Bae, M.-S.; Oh, D.-S.; Kwon, N.-H.; Kim, J.-E.; Choi, C.-Y.; Cho, S. In vitro and in vivo studies on *Quercus acuta* Thunb. (Fagaceae) extract: Active constituents, serum uric acid suppression, and xanthine oxidase inhibitory activity. *Evid. Based Complement. Alternat. Med.* **2017**, *2017*, 4097195. [CrossRef] [PubMed]
51. Youn, U.-Y.; Shon, M.-S.; Kim, G.-N.; Katagiri, R.; Harata, K.; Kamegai, M.; Ishida, Y.; Lee, S.-C. Antioxidant and anti-adipogenic activities of acorn shells. *Food Sci. Biotechnol.* **2016**, *25*, 1183–1187. [CrossRef] [PubMed]
52. Hwang, J.-T.; Choi, H.-K.; Kim, S.H.; Chung, S.; Hur, H.J.; Park, J.; Chung, M.-Y. Hypolipidemic activity of *Quercus acutissima* fruit ethanol extract is mediated by inhibition of acetylation. *J. Med. Food* **2017**, *20*. [CrossRef] [PubMed]
53. Koseki, J.; Matsumoto, T.; Matsubara, Y.; Tsuchiya, K.; Mizuhara, Y.; Sekiguchi, K.; Nishimura, H.; Watanabe, J.; Kaneko, A.; Hattori, T.; et al. Inhibition of Rat 5 α -reductase activity and testosterone-induced sebum synthesis in hamster sebocytes by an extract of *Quercus acutissima* cortex. *Evid.-Based Complement. Altern. Med.* **2015**, *2015*, 853846. [CrossRef] [PubMed]
54. Dettweiler, M.; Lyles, J.; Nelson, K.; Dale, B.; Reddinger, R.; Zurawski, D.; Quave, C. American civil war plant medicines inhibit growth, biofilm formation, and quorum sensing by multidrug-resistant bacteria. *Sci. Rep.* **2019**, *9*. [CrossRef]
55. Whitehead, A.J.; Nelson, N.W.; Brame, L.S.; Champlin, F.R. Endemic north American plants as potentially suitable agents for wound cleaning under resource scarce conditions. *Wilderness Environ. Med.* **2019**, *30*, 401–406. [CrossRef]
56. Karimi, A.; Rafieian-kopaei, M.; Moradi, M.T.; Alidadi, S. Anti-herpes simplex virus Type-1 activity and phenolic content of crude ethanol extract and four corresponding fractions of *Quercus brantii* L Acorn. *J. Evid.-Based Complement. Altern. Med.* **2016**, *22*. [CrossRef]
57. Farhad, M.; Karimi, A.; Alidadi, S. In vitro antiproliferative and apoptosis-inducing activities of crude ethyle alcohole extract of *Quercus brantii* L. acorn and subsequent fractions. *Chin. J. Nat. Med.* **2016**, *14*, 196–202. [CrossRef]
58. Aleebrahim-Dehkordy, E.; Rafieian-kopaei, M.; Amini-Khoei, H.; Abbasi, S. In vitro evaluation of antioxidant activity and antibacterial effects and measurement of total phenolic and flavonoid contents of *Quercus brantii* L. fruit extract. *J. Diet. Suppl.* **2018**, *16*, 1–9. [CrossRef]
59. Abdollahi, P.; Khanavi, M.; Sabbagh-Bani-Azad, M.; Abdolghaffari, A.H.; Vazirian, M.; Isazadeh, I.; Rezvanfar, M.A.; Baeeri, M.; Mohammadirad, A.; Rahimi, R.; et al. On the beneft of galls of *Quercus brantii* Lindl. in murine colitis: The role of free gallic acid. *Arch. Med. Sci.* **2014**, *10*, 1225–1234. [CrossRef]
60. Moshfeghy, Z.; Asadi, K.; Akbarzadeh, M.; Zare, A.; Poordast, T.; Emamghoreishi, M.; Najib, F.; Sayadi, M. *Quercus brantii* Lindl. vaginal douche versus clotrimazole on vaginal candidiasis. *J. Pharmacopunct.* **2018**, *21*, 185–194. [CrossRef]
61. Daryani, A.; Ebrahimzadeh, M.; Taheri, M.; Ahmadpour, E.; Montazeri, M.; Sarvi, S.; Akbari, M. Anti-toxoplasma effects of methanol extracts of Feijoa Sellowiana, *Quercus castaneifolia*, and *Allium paradoxum*. *J. Pharmacopunct.* **2017**, *20*, 220–226. [CrossRef] [PubMed]
62. Pinto, D.; Franco, S.; Silva, A.; Cupara, S.; Koskovac, M.; Kojicic, K.; Soares, S.; Rodrigues, F.; Sut, S.; Dall'Acqua, S.; et al. Chemical characterization and bioactive properties of a coffee-like beverage prepared from: *Quercus cerris* kernels. *Food Funct.* **2019**, *10*, 2050–2060. [CrossRef] [PubMed]

63. Hobby, G.; Quave, C.; Nelson, K.; Compadre, C.; Beenken, K.; Smeltzer, M. *Quercus cerris* extracts limit staphylococcus aureus biofilm formation. *J. Ethnopharmacol.* **2012**, *144*. [CrossRef] [PubMed]
64. Sari, S.; Barut, B.; Özel, A.; Kuruüzüm-Uz, A.; Sohretoglu, D. Tyrosinase and α-Glucosidase potential of compounds isolated from *Quercus coccifera* Bark: In vitro and in silico perspectives. *Bioorg. Chem.* **2019**, *86*. [CrossRef]
65. Valencia, E.; García-Pérez, M.; Garnica Romo, M.G.; Figueroa, J.; Melendez, E.; Salgado-Garciglia, R.; Martinez-Flores, H. Antioxidant properties of polyphenolic extracts from *Quercus laurina, Quercus crassifolia,* and *Quercus scytophylla* bark. *Antioxidants* **2018**, *7*, 81. [CrossRef]
66. Valencia, E.; Martinez-Flores, H.; Garcia-Perez, M.; Melendez, E.; García-Pérez, M. Investigation of the antibacterial activity and subacute toxicity of a *Quercus crassifolia* polyphenolic bark extract for its potential use in functional foods. *J. Food Sci.* **2019**, *84*. [CrossRef]
67. Kim, M.; Yin, J.; Hwang, I.H.; Park, D.H.; Lee, E.K.; Kim, M.J.; Lee, M.W. Anti-acne vulgaris effects of pedunculagin from the leaves of *Quercus mongolica* by anti-inflammatory activity and 5α-Reductase inhibition. *Molecules* **2020**, *25*, 2154. [CrossRef]
68. Ahmed, M.; Adil, M.; Haq, I.; Tipu, M.K.; Qasim, M.; Gul, B. RP-HPLC-based phytochemical analysis and diverse pharmacological evaluation of *Quercus floribunda* Lindl. Ex A. camus nuts extracts. *Nat. Prod. Res.* **2019**. [CrossRef]
69. Youn, S.; Kwon, J.; Yin, J.; Tam, L.; Ahn, H.; Myung, S.; Lee, M. Anti-inflammatory and anti-urolithiasis effects of polyphenolic compounds from *Quercus gilva* blume. *Molecules* **2017**, *22*, 1121. [CrossRef]
70. Shen, C.-C.; Chen, J.; Zhang, L.-J.; Lin, Z.-H.; Huang, H.-T.; Cheng, H.-L.; Kuo, Y.-H. Antioxidant and anti-nitric oxide components from *Quercus glauca*. *Chem. Pharm. Bull. (Tokyo)* **2012**, *60*, 924–929. [CrossRef] [PubMed]
71. Rtibi, K.; Hammami, I.; Selmi, S.; Grami, D.; Sebai, H.; Mohamed, A.; Marzouki, L. Phytochemical properties and pharmacological effects of *Quercus ilex* L. aqueous extract on gastrointestinal physiological parameters *in vitro* and *in vivo*. *Biomed. Pharmacother.* **2017**, *94*, 787–793. [CrossRef] [PubMed]
72. Castejón Martínez, L.; Rosillo, M.; Villegas, I.; Sánchez-Hidalgo, M.; Hadidi, L.; Zaidi, F.; Lastra, C. *Quercus ilex* extract ameliorates acute TNBS-induced colitis in rats. *Planta Med.* **2019**, *85*. [CrossRef] [PubMed]
73. Vargas-Segura, A.; Silva-Belmares, S.; Segura-Ceniceros, E.; Ascacio-Valdés, J.; Méndez-González, L.; Ilyina, A. Screening and characterization of medicinal plants extracts with bactericidal activity against *Streptococcus mutans*. *Nat. Prod. Res.* **2019**. [CrossRef]
74. Gul, F.; Khan, K.; Adhikari, A.; Zafar, S.; Akram, M.; Khan, H.; Saeed, M. Antimicrobial and antioxidant activities of a new metabolite from *Quercus incana*. *Nat. Prod. Res.* **2016**, *31*, 1–9. [CrossRef]
75. Hasan, B.Z.; Ahmed, A.; Khan, A. Apoptotic and antimetastatic activities of betulin isolated from *Quercus incana* against non-small cell lung cancer cells. *Cancer Manag. Res.* **2019**, *2019*, 1667.
76. Chusri, S.; Na-Phatthalung, P.; Voravuthikunchai, S. Anti-biofilm activity of *Quercus infectoria* G. olivier against methicillin-resistant *Staphylococcus Aureus*. *Lett. Appl. Microbiol.* **2012**, *54*, 511–517. [CrossRef]
77. Kheirandish, F.; Delfan, B.; Mahmoudvand, H.; Moradi, N.; Ezatpour, B.; Ebrahimzadeh, F.; Rashidipour, M. Antileishmanial, antioxidant, and cytotoxic activities of *Quercus infectoria* olivier extract. *Biomed. Pharmacother.* **2016**, *82*, 208–215. [CrossRef]
78. Tayel, A.A.; El-Sedfy, M.A.; Ibrahim, A.I.; Moussa, S.H. Application of *Quercus infectoria* extract as a natural antimicrobial agent for chicken egg decontamination. *Rev. Argent. Microbiol.* **2018**, *50*, 391–397. [CrossRef]
79. Khairon, R.; Zin, N.M.; Rahman, M.A.; Basri, D.F. Comparative proteomic analysis of differential proteins in response to aqueous extract of *Quercus infectoria* gall in methicillin-resistant staphylococcus aureus. *Int. J. Proteomics* **2016**, *2016*, 4029172. [CrossRef]
80. Basri, D. Evaluation of analgesic activity of the methanol extract from the galls of *Quercus infectoria* (Olivier) in rats. *Evid. Based Complement. Alternat. Med.* **2014**, *2014*. [CrossRef]
81. Sengupta, R.; Sheorey, S.D.; Hinge, M. Analgesic and anti-inflammatory plants: An updated review. *Int. J. Pharm. Sci. Rev. Res.* **2012**, *12*, 114–119.
82. Iminjan, M.; Amat, N.; Li, X.-H.; Upur, H.; Ahmat, D.; He, B. Investigation into the toxicity of traditional uyghur medicine *Quercus infectoria* galls water extract. *PLoS ONE* **2014**, *9*. [CrossRef] [PubMed]
83. Karbasizade, V.; Dehghan, P.; Mohammadi Sichani, M.; Shahanipour, K.; Sepahvand, S.; Jafari, R.; Yousefian, R. Evaluation of three plant extracts against biofilm formation and expression of quorum sensing regulated virulence factors in Pseudomonas Aeruginosa. *Pak. J. Pharm. Sci.* **2017**, *30*, 585–589. [PubMed]

84. Yarani, R.; Mansouri, K.; Mohammadi-Motlagh, H.-R.; Mahnam, A.; Aleagha, M.S.E. In vitro inhibition of angiogenesis by hydroalcoholic extract of oak (*Quercus infectoria*) acorn shell via suppressing VEGF, MMP-2, and MMP-9 secretion. *Pharm. Biol.* **2012**, *51*. [CrossRef]
85. Basri, D.; Khairon, R. Pharmacodynamic interaction of *Quercus infectoria* galls extract in combination with vancomycin against MRSA using microdilution checkerboard and time-kill assay. *Evid.-Based Complement. Altern. Med.* **2012**, *2012*, 493156. [CrossRef]
86. Tayel, A.A.; El-Tras, W.F.; Abdel-Monem, O.A.; El-Sabbagh, S.M.; Alsohim, A.S.; El-Refai, E.M. Production of anticandidal cotton textiles treated with oak gall extract. *Rev. Argent. Microbiol.* **2013**, *45*, 271–276. [CrossRef]
87. Ahmed, A.; Salih, F. *Quercus* infectoria gall extracts reduce quorum sensing-controlled virulence factors production and biofilm formation in pseudomonas aeruginosa recovered from burn wounds. *BMC Complement. Altern. Med.* **2019**, *19*. [CrossRef]
88. Chokpaisarn, J.; Urao, N.; Voravuthikunchai, S.; Koh, T. *Quercus infectoria* inhibits Set7/NF-KB inflammatory pathway in macrophages exposed to a diabetic environment. *Cytokine* **2017**, *94*. [CrossRef]
89. Abdullah, A.R.; Hapidin, H.; Abdullah, H. The role of semipurified fractions isolated from Quercus infectoria on bone metabolism by using HFOB 1.19 human fetal osteoblast cell model. *Evid. Based Complement. Alternat. Med.* **2018**, *2018*, 5319528. [CrossRef]
90. Sati, S.; Sati, N.; Sati, O.P.; Biswas, D.; Chauhan, B.S. Analysis and antimicrobial activity of volatile constituents from *Quercus leucotrichophora* (Fagaceae) bark. *Nat. Prod. Res.* **2011**, *26*, 869–872. [CrossRef]
91. Sati, A.; Sati, S.C.; Sati, N.; Sati, O.P. Chemical composition and antimicrobial activity of fatty acid methyl ester of *Quercus leucotrichophora* fruits. *Nat. Prod. Res.* **2017**, *31*, 713–717. [CrossRef] [PubMed]
92. Paswan, V.K.; Sahoo, A. Feeding of oak (*Quercus leucotrichophora*) leaves and evaluation for its potential inclusion in the feeding of native heifers of Kumaon Himalaya. *Trop. Anim. Health Prod.* **2012**, *44*. [CrossRef] [PubMed]
93. Yin, J.; Kim, H.H.; Hwang, I.H.; Kim, D.H.; Lee, M.W. Anti-inflammatory effects of phenolic compounds isolated from *Quercus mongolica* fisch. Ex Ledeb. on UVB-irradiated human skin cells. *Molecules* **2019**, *24*, 3094. [CrossRef] [PubMed]
94. Kim, H.; Kim, D.H.; Oh, M.; Park, K.; Heo, J.; Lee, M.-W. Inhibition of matrix Metalloproteinase-1 and Type-I procollagen expression by phenolic compounds isolated from the leaves of *Quercus mongolica* in ultraviolet-irradiated human fibroblast cells. *Arch. Pharm. Res.* **2014**, *38*. [CrossRef]
95. Yin, P.; Wang, Y.; Yang, L.; Sui, J.; Liu, Y. Hypoglycemic effects in alloxan-induced diabetic rats of the phenolic extract from mongolian oak cups enriched in ellagic acid, kaempferol and their derivatives. *Molecules* **2018**, *23*, 1046. [CrossRef]
96. Panchal, S.K.; Brown, L. Cardioprotective and hepatoprotective effects of ellagitannins from european oak bark (*Quercus petraea* L.) extract in rats. *Eur. J. Nutr.* **2013**, *52*, 397–408. [CrossRef]
97. Dania, V.O.; Fadina, O.O.; Ayodele, M.; Kumar, P.L. Efficacy of *Oryza sativa* husk and *Quercus phillyraeoides* extracts for the *in Vitro* and *in Vivo* control of fungal rot disease of white yam (Dioscorea Rotundata Poir). *SpringerPlus* **2014**, *3*, 711. [CrossRef]
98. Castro, L.; Alanon, M.; Ricardo-da-Silva, J.; Pérez-Coello, M.; Laureano, O. Evaluation of portuguese and spanish *Quercus pyrenaica* and *Castanea sativa* species used in cooperage as natural source of phenolic compounds. *Eur. Food Res. Technol.* **2013**, *237*. [CrossRef]
99. Natella, F.; Leoni, G.; Maldini, M.; Natarelli, L.; Comitato, R.; Schonlau, F.; Virigil, F.; Canali, R. Absorbtion, metabolisation and effects at transcriptome level of a standardised french oak wood extract Robuvit®in healthy volunteers: A pilot study. *J. Agric. Food Chem.* **2013**, *62*. [CrossRef]
100. Országhová, Z.; Waczulíková, I.; Burki, C.; Rohdewald, P.; Ďuračková, Z. An effect of oak-wood extract (Robuvit®) on energy state of healthy adults—A pilot study. *Phytother. Res.* **2015**, *29*, 1219–1224. [CrossRef] [PubMed]
101. Deryabin, D.G.; Tolmacheva, A.A. Antibacterial and anti-quorum sensing molecular composition derived from *Quercus cortex* (Oak Bark) extract. *Molecules* **2015**, *20*, 17093–17108. [CrossRef] [PubMed]
102. Duskaev, G.; Rakhmatullin, S.; Kazachkova, N.; Sheida, Y.; Mikolaychik, I.; Morozova, L.; Galiev, B. Effect of the combined action of *Quercus cortex* extract and probiotic substances on the immunity and productivity of broiler chickens. *Vet. World* **2018**, *11*, 1416–1422. [CrossRef] [PubMed]

103. Belcaro, G.; Dugall, M.; Hu, S.; Ledda, A.; Ippolito, E. French oak wood (*Quercus Robur*) extract (Robuvit) in primary lymphedema: A supplement, pilot, registry evaluation. *Int. J. Angiol. Off. Publ. Int. Coll. Angiol. Inc* **2015**, *24*, 47–54. [CrossRef]
104. Belcaro, G.; Saggino, A.; Cornelli, U.; Luzzi, R.; Dugall, M.; Hosoi, M.; Feragalli, B.; Cesarone, M. Improvement in mood, oxidative stress, fatigue, and insomnia following supplementary management with Robuvit®. *J. Neurosurg. Sci.* **2018**, *62*, 423–427. [CrossRef]
105. López-Hortas, L.; Falqué, E.; Domínguez, H.; Torres, M.D. Microwave Hydrodiffusion and Gravity (MHG) extraction from different raw materials with cosmetic applications. *Molecules* **2019**, *25*, 92. [CrossRef]
106. Jiménez-Moreno, N.; Moler, J.; Urmeneta, H.; Suberviola-Ripa, J.; Cibriain-Sabalza, F.; Gandía, L.M.; Ancín-Azpilicueta, C. Oak wood extracts applied to the grapevine. An alternative to obtain quality garnacha wines. *Food Res. Int.* **2017**, *105*. [CrossRef]
107. Uddin, G.; Rauf, A. Phytochemical screening, antimicrobial and antioxidant activities of aerial parts of *Quercus Robur* L. *J. Med. Plants Res.* **2012**. [CrossRef]
108. Azeem, M.; Borg-Karlson, A.K.; Rajarao, G.K. Sustainable bio-production of styrene from forest waste. *Bioresour. Technol.* **2013**, *144*, 684–688. [CrossRef]
109. Focant, M.; Froidmont, E.; Archambeau, Q.; Van, Q.C.; Larondelle, Y. The effect of oak tannin (*Quercus robur*) and hops (*Humulus lupulus*) on dietary nitrogen efficiency, methane emission, and milk fatty acid composition of dairy cows fed a low-protein diet including linseed. *J. Dairy Sci.* **2018**, *102*. [CrossRef]
110. Honarmand, S.; Dabirmanesh, B.; Amanlou, M.; Khajeh, K. The interaction of several herbal extracts with α-synuclein: Fibril formation and surface plasmon resonance analysis. *PLoS ONE* **2019**, *14*, e0217801. [CrossRef] [PubMed]
111. Muccilli, V.; Cardullo, N.; Spatafora, C.; Cunsolo, V.; Tringali, C. α-Glucosidase inhibition and antioxidant activity of an oenological commercial tannin. Extraction, fractionation and analysis by HPLC/ESI-MS/MS and 1H NMR. *Food Chem.* **2017**, *215*, 50–60. [CrossRef] [PubMed]
112. Park, S.-H.; Kim, H.-J.; Yoon, J.-S.; Lee, H.-W.; Park, G.-C.; Yi, E.; Yoon, G.; Schini-Kerth, V.; Oak, M.-H. The effect of *Quercus salicina* leaf extracts on vascular endothelial function: Role of nitric oxide. *J. Nanosci. Nanotechnol.* **2016**, *16*, 2069–2071. [CrossRef] [PubMed]
113. Mai, Y.; Wang, Z.; Wang, Y.; Xu, J.; He, X. Anti-neuroinflammatory triterpenoids from the seeds of *Quercus serrata* thunb. *Fitoterapia* **2020**, *6142*, 104523. [CrossRef]
114. Rosales-Castro, M.; González-Laredo, R.F.; Rocha-Guzmán, N.E.; Gallegos-Infante, J.A.; Rivas-Arreola, M.J.; Karchesy, J.J. Antioxidant activity of fractions from *Quercus sideroxyla* bark and identification of proanthocyanidins by HPLC-DAD and HPLC-MS. *Holzforschung* **2012**, *66*, 577–584. [CrossRef]
115. Soto, M.; Rosales-Castro, M.; Escalona-Cardoso, G.; Paniagua, N. Evaluation of hypoglycemic and genotoxic effect of polyphenolic bark extract from *Quercus sideroxyla*. *Evid. Based Complement. Alternat. Med.* **2016**, *2016*, 4032618. [CrossRef]
116. Aroso, I.; Araújo, A.R.; Fernandes, J.; Santos, T.; Batista, M.; Pires, R.; Mano, J.F.; Reis, R.L. Hydroalcoholic extracts from the bark of *Quercus suber* L. (Cork): Optimization of extraction conditions, chemical composition and antioxidant potential. *Wood Sci. Technol.* **2017**, *51*. [CrossRef]
117. Gonçalves, F.; Correia, P.; Silva, S.; Aguiar, C.A. Evaluation of antimicrobial properties of cork. *FEMS Microbiol. Lett.* **2015**, *363*, fnv231. [CrossRef]
118. Zhou, D.; Liu, Z.-H.; Wang, D.-M.; Li, D.-W.; Yang, L.-N.; Wang, W. Chemical composition, antibacterial activity and related mechanism of valonia and shell from *Quercus variabilis* blume (Fagaceae) against *Salmonella Paratyphi* a and *Staphylococcus Aureus*. *BMC Complement. Altern. Med.* **2019**, *19*. [CrossRef]
119. Sorrentino, E.; Succi, M.; Tipaldi, L.; Pannella, G.; Maiuro, L.; Sturchio, M.; Coppola, R.; Tremonte, P. Antimicrobial activity of gallic acid against food-related pseudomonas strains and its use as biocontrol tool to improve the shelf life of fresh black truffles. *Int. J. Food Microbiol.* **2017**, *266*. [CrossRef]
120. Hemingway, R.W.; Laks, P.E. *Plant Polyphenols: Synthesis, Properties, Significance*, 1st ed.; Springer: Berlin/Heidelberg, Germany, 1992; Volume 59.
121. Chung, K.-T.; Wong, T.Y.; Wei, C.-I.; Huang, Y.-W.; Lin, Y. Tannins and human health: A review. *Crit. Rev. Food Sci. Nutr.* **1998**, *38*, 421–464. [CrossRef] [PubMed]
122. Akiyama, H.; Fujii, K.; Yamasaki, O.; Oono, T.; Iwatsuki, K. Antibacterial action of several tannins against *Staphylococcus aureus*. *J. Antimicrob. Chemother.* **2001**, *48*, 487–491. [CrossRef] [PubMed]

123. Baliga, M.S.; Shivashankara, A.R.; Venkatesh, S.; Bhat, H.P.; Palatty, P.L.; Bhandari, G.; Rao, S. Chapter 7 - phytochemicals in the prevention of ethanol-induced hepatotoxicity: A revisit. In *Dietary Interventions in Liver Disease*; Watson, R.R., Preedy, V.R., Eds.; Academic Press: Cambridge, MA, USA, 2019; pp. 79–89. [CrossRef]
124. Calderón-Montaño, J.; Burgos-Morón, E.; Pérez-Guerrero, C.; López-Lázaro, M. A review on the dietary flavonoid kaempferol. *Mini Rev. Med. Chem.* **2011**, *11*, 298–344. [CrossRef] [PubMed]
125. Cui, Y.; Morgenstern, H.; Greenland, S.; Tashkin, D.P.; Mao, J.T.; Cai, L.; Cozen, W.; Mack, T.M.; Lu, Q.-Y.; Zhang, Z.-F. Dietary flavonoid intake and lung cancer—A population-based case-control study. *Cancer* **2008**, *112*, 2241–2248. [CrossRef] [PubMed]
126. Sultana, B.; Anwar, F. Flavonols (kaempeferol, quercetin, myricetin) contents of selected fruits, vegetables and medicinal plants. *Food Chem.* **2008**, *108*, 879–884. [CrossRef]
127. Rios, J.-L.; Giner, R.; Marin, M.; Recio, M. A pharmacological update of ellagic acid. *Planta Med.* **2018**, *84*. [CrossRef]
128. Tafesse, T.; Hymete, A.; Mekonnen, Y.; Mohammed, M. antidiabetic activity and phytochemical screening of extracts of the leaves of *Ajuga remota* benth on alloxan-induced diabetic mice. *BMC Complement. Altern. Med.* **2017**, *17*, 243. [CrossRef]
129. Rocha-Guzmán, N.E.; González-Laredo, R.F.; Vázquez-Cabral, B.D.; Moreno-Jiménez, M.R.; Gallegos-Infante, J.A.; Gamboa-Gómez, C.I.; Flores-Rueda, A.G. 11—Oak leaves as a new potential source for functional beverages: Their antioxidant capacity and monomer flavonoid composition. In *Functional and Medicinal Beverages*; Grumezescu, A.M., Holban, A.M., Eds.; Academic Press: Cambridge, MA, USA, 2019; pp. 381–411. [CrossRef]
130. Wang, T.; Li, X.; Zhou, B.; Li, H.; Zeng, J.; Gao, W. Anti-diabetic activity in Type 2 diabetic mice and α-glucosidase inhibitory, antioxidant and anti-inflammatory potential of chemically profiled pear peel and pulp extracts (*Pyrus* spp.). *J. Funct. Foods* **2015**, *13*, 276–288. [CrossRef]
131. Shen, S.-C.; Chang, W.-C. Hypotriglyceridemic and hypoglycemic effects of vescalagin from pink wax apple [*Syzygium Samarangense* (blume) Merrill and Perry cv. Pink] in high-fructose diet-induced diabetic rats. *Food Chem.* **2013**, *136*, 858–863. [CrossRef]
132. Sindt, L.; Gammacurta, M.; Waffo-Téguo, P.; Dubourdieu, D.; Marchal, A. Taste-guided isolation of bitter lignans from *Quercus petraea* and their identification in wine. *J. Nat. Prod.* **2016**, *79*. [CrossRef]
133. Hwang, J.T.; Park, I.J.; Shin, J.I.; Lee, Y.K.; Lee, S.K.; Baik, H.W.; Ha, J.; Park, O.J. Genistein, EGCG, and capsaicin inhibit adipocyte differentiation process via activating AMP-activated protein kinase. *Biochem. Bioph. Res. Commun.* **2005**, *338*, 694–699. [CrossRef] [PubMed]