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Review

An Overview of Oak Species in Pakistan: Past, Present, and Future Research Perspectives

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Abstract: *Quercus* spp. have formed broad-leaved evergreen forests in the Hindu Kush and Himalayan regions of Pakistan. Seven species of the genus *Quercus* (*Q. baloot* Griff., *Q. dilatata* Royle., *Q. glauca* Thunb., *Q. incana* Roxb., *Q. robur* Linn., *Q. semecarpifolia* Smith., and *Q. leucotrichophora* A. Camus.) have been identified. These species have received little attention compared with other economically valuable plant species in Pakistan, which has been mainly linked to traditional medicine and the identification of phytonutrients to evaluate their bioactivities and toxicological effects. *Quercus* spp. are promising for commercial applications, so government policy should encourage their management and conservation. However, they are currently threatened by severe human activities and climate change. The goal of this review is to highlight the relevance of these forgotten species, describing overall aspects related to their distribution, morphology, traditional uses, phytochemical constituents, and threats. To date, no proper and comprehensive molecular studies on the populations of these species found in Pakistan have been conducted, which is a critical gap as molecular studies are essential for conservation and management strategies. Finally, we discuss future directions in molecular approaches for *Quercus* that follow the strategies that are being used for other species of the genus *Quercus* that are not found in Pakistan.

Keywords: *Quercus* spp.; conservation; management; climate change; bioactive phytochemicals

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1. Introduction

Quercus L., belonging to the family *Fagaceae*, is considered an ecologically and economically important genus in the deciduous and evergreen forest ecosystems in the Northern Hemisphere [1], formed by more than 500 species [2–7]. *Quercus* species are commonly found in Asia, Europe, North America, and Africa because of their high ability to adapt to a variety of climatic and soil conditions [7]. European (Bulgaria, Portugal, Romania, Italy, and Spain), American (Canada, U.S., and Mexico), and Asian countries (Afghanistan, China, Mongolia, Nepal, Russia, Japan, India, and Pakistan) have particularly high abundances of these species. *Quercus* spp. are ubiquitous in temperate climate forests and are found in well-drained areas, often in highlands areas, with some species, such as *Quercus lyrata* Walter., and *Quercus laurifolia* Michx., being tolerant of flooding [8]. They are also found in typical agrosilvopastoral systems, such as the Spanish "*dehesa*" and the Portuguese "*montado*", where *Quercus ilex* L. and *Quercus suber* L. are the dominant species, respectively [9–11]. Forest trees, such as oaks, are long-lived organisms that have played a crucial role in human life since earlier human civilization [12]. They are important components of the Earth's health and ecosystems, being involved in our culture and spiritual practices and used for a wide range of goods and services [7]. They must be preserved as irreplaceable cultural heritage for subsequent generations. However, humankind is constantly deforesting, clearing, or shrinking oak forest areas [7].

Quercus spp. play critical roles in ecosystem normal functioning (such as the upkeep of biodiversity, water and soil conservation, and carbon sequestration) and offer raw materials for timber, starch, tannin, cork, and medicines [1–4]. A few oaks, such as *Quercus palustris* Münchh. and *Quercus rubra* L., are prized for their ornamentation value in North America [13]. White oak (*Quercus alba* L.) and bur oak (*Q. macrocarpa* Michx.) frame oak forests in the midwest USA [13]. The galls that develop on the twigs of the Aleppo oak (*Q. infectoria* Olivier.) are a source of Aleppo tannin, which is used in ink manufacturing; commercial cork is obtained from the bark of *Q. suber*; and the tannin-rich kermes oak (*Quercus coccifera* L.) is the host of the kermes insect, which was once collected for a color in its bodily liquids. Mongolian oak (*Quercus mongolica* Fisch. ex Ledeb.) and Oriental oak (*Q. variabilis* Blume.) are the two most economically important eastern Asian oak species [13]. Mongolian oak is an excellent source of timber, and Oriental oak is a source of black dye and an ornamental tree [13]. Other developed ornamental oaks include the pontic oaks (*Quercus pontica* K.Koch., *Quercus castaneaefolia* C.A.Mey., *Quercus alnifolia* Poech, *Quercus frainetto* Ten., and *Quercus libani* Olivier, among others). The predominant Asian ornamentals include the blue Japanese oak *Quercus glauca* (Thunb.), daimyo oak (*Quercus dentata* Thunb.), and sawtooth oak (*Quercus acutissima* Carruth.) [13]. *Quercus* trees are essential for maintaining healthy soil conditions, thus improving soil quality [14–16]. Their roots and associated soil microbiomes, prevent soil erosion, and preserve water resources. Furthermore, when *Quercus* leaves fall from trees or the tree dies, they decompose and fertilize the soil, allowing other plants to grow and thrive [7]. *Quercus* spp. wood plays a substantial role in the wood industry for its color, durability, and resistance to fungal decay [17,18]. *Quercus* tree products, such as acorns, bark, timber, and leaves, have numerous applications [14,19]. Furniture, railroad ties, barrels, tool handles, and veneers are all produced from the hard, appealingly granular wood of *Quercus* spp. [15,19,20]. Moreover, the bark, leaves, and roots contain many tannins and are employed to produce leather. Similarly, the bark of *Quercus* spp. can be dried and used for therapeutic purposes [21]. Oak species produce a widely recognized fruit (acorn), which, along with the bark and leaves, has been used in folk medicine as a disinfectant or to treat digestive problems [15,16]. Acorns are used as food for both humans and animals because of their nutritional value [14]. The acorns are ground into flour or roasted to produce acorn coffee [17].

In Pakistan, the value and importance of wild plants, particularly oak species, are frequently overlooked. *Quercus* trees may appear to be insignificant in our daily lives, but they are essential for life and our long-term survival. Oaks are an indispensable asset; people rely on them for food, water, medicine, the air we breathe, habitat, and climate, among many others. Furthermore, oaks play a critical role in providing a habitat for a wide range of species [7], more than any other native tree, being home to hundreds of insects and providing food for birds and mammals in Pakistan. Oaks host fungi, lichens, and even bats. Native wildlife relies on native plant and tree species, such as the *Quercus*, to survive. However, deforestation and climatic change are now threatening the survival of *Quercus* spp. in Pakistan [16].

To the best of our knowledge, this is the first review describing the gaps in the literature on the importance of and the threats faced by *Quercus* spp. in Pakistan. Illegal cutting for fuel and the timber trade has negatively impacted the oak resources of Pakistan [22]. *Quercus* growth and development are also influenced by an increased frequency and severity of mountainous fires in Pakistan [16,22]. Trees of the genus *Quercus* are important in Pakistan; however, their importance in the forest composition is not well understood. Furthermore, the climatic and anthropogenic factors threatening various *Quercus* spp. have not been thoroughly studied in Pakistan. Future *Quercus* projects should be designed to gain a further understanding of and identify the major threats to oak species in Pakistan. This review assists in understanding the conservation, development, and use of oak, highlighting the current status of, threats to, and conservation problems facing these forest species in Pakistan.

2. Description of *Quercus* Species in Pakistan

To date, a total of seven species of the genus *Quercus* have been identified in Pakistan, which are *Q. baloot* Griff., *Q. dilatata* Royle., *Q. glauca* Thunb., *Q. incana* Roxb., *Q. robur* Linn., *Q. semecarpifolia* Smith., and *Q. leucotrichophora* A. Camus (http://www.efloras.org/ (accessed on 8 January 2023) *Quercus* in Flora of Pakistan @ efloras.org) [23]. *Q. glauca* belongs to the section *Cyclobalanopsis*, *Q. robur* belongs to the section *Quercus*, and the rest of the species belongs to the section *Ilex* [24]. Notably, *Q. robur* is an exotic species [15,17,19]. We next provide a detailed description of these *Quercus* spp., with a detailed comparison of their morphology provided in Table 1.

Quercus baloot, locally called shah baloot, banjkarori, or banj, is a small and hardy evergreen tree that grows to a height of 2.5–8 m, with greyish tomentose young branches, found in the dry inner Hindukush and Himalayas valleys between 1800 and 3000 m above sea level [14,17] and typically gregarious and frequently associated with blue pines (*Pinus wallichiana* A.B.Jacks.). *Q. baloot* is observed in nature to hybridize with *Q. dilatata*, which is smaller, with tomentose leaves, and grows in drier ecosystems [17]. Leaves are oblong-ovate to obovate or elliptic or suborbiculate, entire. The upper surface of the leaf is green, whereas the lower surface is pale green, as shown in Figure 1A. The wood is used in construction, and the bark produces tannin [17,18]. *Q. baloot* flowers from April to May [14].

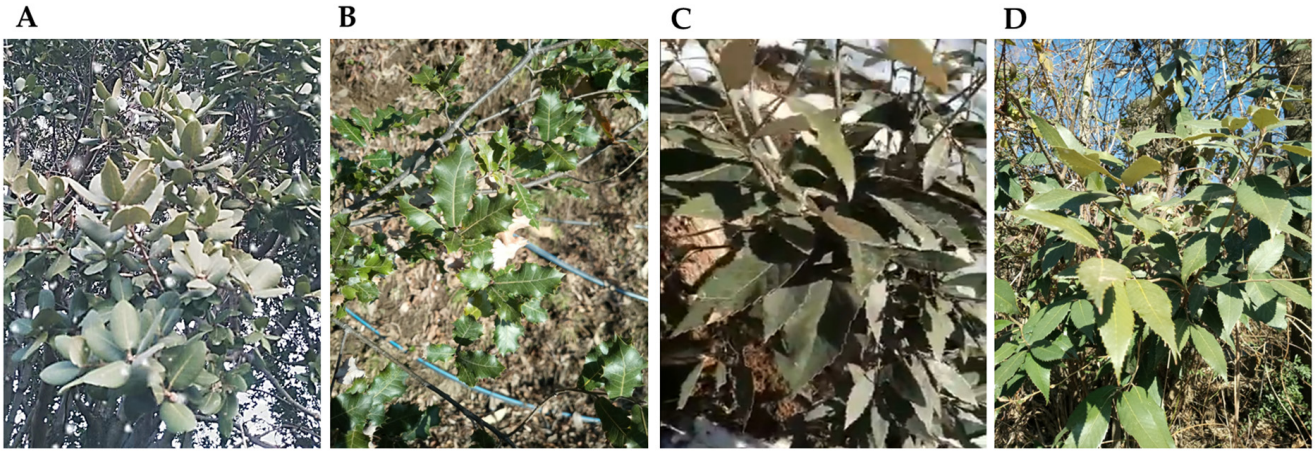

Figure 1. Representation of leaves of some oak species in Pakistan: (**A**) *Q. baloot* Griff., (**B**) *Q. dilatata* Royle., (**C**) *Q. glauca* Thunb., and (**D**) *Q. incana* Roxb. The photos were provided by Muhammad Khalil Ullah Khan.

Quercus dilatata, also known as holly oak, is locally known as bunj or barungi [15,17,19,25]. The tree grows up to 20 m tall. The leaves are usually elliptic-ovate to broadly lanceolate coriaceous, entire to spiny-toothed. Both surfaces of the leaves are green and glabrous; the base is often oblique, and the petiole is 0.3–1 cm long. The species can be distinguished from others by its bifacial green leaves [17,19,22] (Figure 1B). *Q. dilatata* also flowers from April to May. Sometimes a mixed type between *Q. dilatata* and *Q. baloot* can be observed, having leaves resembling those of both *Q. dilatata* and *Q. baloot* (Figure 2). This may be a result of the intercrosses between *Q. dilatata* and *Q. baloot*.

Quercus glauca trees can grow up to 18 m tall. The leaves are 7–16 × 2.0–6 cm, and the petiole can be up to l.4–2.3 mm long. The leaves are acuminate, dull green above and glaucous green pubescent below, neither coriaceous nor entire or serrate, and with serrations exclusively on the top half [17,18]. *Q. glauca* flowers from March to April (Figure 1C).

Quercus incana locally known as serai or banj, is a classic moist temperate oak with gregarious development. Trees range in height from 6 to 18 m. Winter buds are 1.5–2 cm long and encased in brown scales [15,17]. Leaves are elliptic-lanceolate to ovate-lanceolate, roughly chopped serrate but not at the base, acuminate, and with a dark green upper

surface and white tomentose lower surface. The petiole is 0.4–1.5 cm long [26] (Figure 1D). *Q. incana* flowers from April to May and fruits from August to September [17].

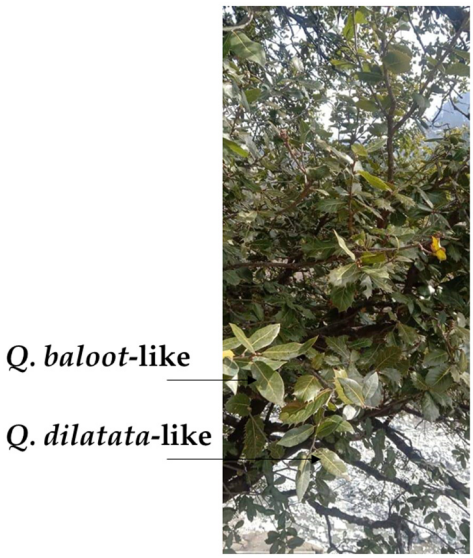

Figure 2. *Quercus* tree showing mixed *Q. baloot* Griff. and *Q. dilatata* Royle leaves. The photo was provided by Muhammad Khalil Ullah Khan.

Regarding *Quercus leucotrichophora*, the word leucotrichophora means "which has white hairs". This species is locally called banj *Q. leucotrichophora* and can attain a height of 15–25 m. The canopy of the banj oak is full and rounded. The bark is originally smooth and tan-brown, but as it matures, it develops a faint brow furrow and becomes corky [23]. The leaves are elongated ovals with alternating rows of razor-sharp teeth. When leaves are young, they are pink-purple, and as they mature, the top surface usually turns deep green, whereas the lower side is silvery grey. The fruits are marble-sized, orange-tan acorns [23]. *Q. leucotrichophora* blooms from April to May and bears fruit in December.

Quercus robur species are locally known as banj. The tree grows 25 m or taller. Leaves are ovate, 3.5–11.5 cm long, the upper surface is dark green, and the lower surface is pale green. The petiole is 4–6 mm in length [17,19]. Male flowers occur in catkins. Acorns are 2–2.4 cm long [17,19]. *Q. robur* flowers in April–May. It thrives in areas with light snowfall [19]. The size, shape, and degree of incision of the leaves vary from tree to tree. *Q. robur* intercrosses with other *Quercus* spp., resulting in a wide range of intermediates [27–29].

Quercus semecarpifolia, also known as khar banj, is an Asian oak tree. It is an evergreen tree that can grow up to 20–30 m tall and is sometimes shrubby [17,30]. The young shoots are usually tomentose. The leaves can reach a length of 12 cm, with a few teeth along the margins and a rounded apex [18,19]. Leaves are oblong to elliptic-oblong, with a margin entire to spinose [16,18]. It flowers between May and June and is found in Himalayan climax communities. *Q. semecarpifolia* is one of the earliest vegetation types in this region [31,32]. Larger trees are frequently hollow, with silky hairs covering the juvenile parts. Whenever the oak fruit ripens, a large amount of food is provided for many forest animals. If an acorn is left uneaten, it sprouts tiny shoots and roots in any fertile soil, resulting in a new seedling tree and restarting the cycle of life and growth [33].

Distribution of Quercus Species in Pakistan

Pakistan has a wide variety of forests, ranging from high-altitude alpine scrub to sea-coast mangrove forests [34]. Oak forests are the most important of these forest types because they are intimately associated with the watersheds of the country's upland areas, including the fragile ecosystems of the Himalayas, Hindu-Kush, and Gilgit Baltistan's northern mountainous ranges [34,35]. These forests cover a large portion of the country and the Hindu-Kush ranges, totaling 2.043 million ha in the province of Khyber Pakhtunkhwa

and 4.2 million ha in Pakistan in total [18,19]. The exact figures for the area of *Quercus* are not available; however, the estimated *Quercus* forest area is more than 100,000 ha in Pakistan, of which a 16,700 ha area comprises only oak species in the district of Chitral in Khyber Pakhtunkhwa province [35,36]. Pakistan is located in a temperate zone, and its climate varies as much as the country's topography, being usually dry and hot near the coast and along the Indus River lowland plains and becoming progressively cooler in the northern uplands of Hindu-Kush and the Himalayas. In Pakistan, *Quercus*-dominated forests are primarily found in dry temperate zones ranging from 1200 to 3000 m above sea level, where they form pure communities or are admixed with coniferous forests at higher altitudes [14,16]. Among many of the oak species, both *Q. baloot* and *Q. incana* are prevalent in dry temperate climates; *Q. semecarpifolia* and *Q. dilatata* are more frequent in moist temperate regions. Both *Q. semecarpifolia* and *Q. dilatata* require a summer monsoon. Their forests can be found at altitudes ranging from 1600 to 2900 m in the valleys of Nelum, Jehlum, Konhar, Swat, Dir, and Kohisofaid. *Q. glauca* is the least frequent in moist temperate zones [16]. *Q. robur* has been cultivated in the country's mountainous regions [16]. *Q. leucotrichophora* has been reported in Dir (L) KP, Pakistan [23]. The locations of these oak species in Pakistan are presented in Figure 3.

Table 1. Comparative morphological descriptions of seven oak species found in Pakistan.

Sp. No	Spp.	Local Name	Height	Flowering Time	Fruit Length	Petiole Length	Leaves				Elevation	References
							Color		Shape	Margin		
							Lower Surface	Upper Surface				
1	*Quercus baloot*	Shah baloot, banjkarori, or banj	2.5–8 m	April–May	1–2.5 cm	0.3–0.4 cm	green	pale green	Oblong-ovate to obovate or elliptic or sub-orbiculate	entire	1800–3000 m	[14,17]
2	*Q. dilatata*	Bunj or barungi	20 m	April–May	1.5–2.5	0.3–1 cm	green	green	Elliptic-ovate to broadly lanceolate coriaceous	spiny toothed	1600 to 2900 m	[17,19,22]
3	*Q. glauca*		18 m	March–April	1.8 cm	0.5–1 cm	dull green	whitish pubescent	Oblong, elliptic, to obovate-oblong	entire or serrate	1200–2700 m	[17,18]
4	*Q. incana*	Serai or banj	6–18 m	April–May	1–2 cm	0.4–1.5 cm	dark green	white tomentose	Elliptic-lanceolate to ovate-lanceolate	roughly chopped serrate	1500–2900 m	[15,17,26]
5	*Q. leucotrichophora*	Banj	15–25 m	April–May	1–2.5 cm	1–2.5 cm	deep green	silvery grey	Oblong-lanceolate or narrowly oval		1200–2800 m	[23]
6	*Q. robur*	Banj		April–May	2–2.4 cm	0.4–0.6 cm	dark green	pale green	Oblong to elliptic-oblong	lined with 8–15 acuminate teeth	2200 m	[17,19,27–29]
7	*Q. semecarpifolia*	Khar Banj	20–30 m	May–June	2.5 cm	0.2–0.6 cm	green and glabrescent		Oblong to elliptic-oblong	entire to spinose	1600 to 2900 m	[16,18,19,33]

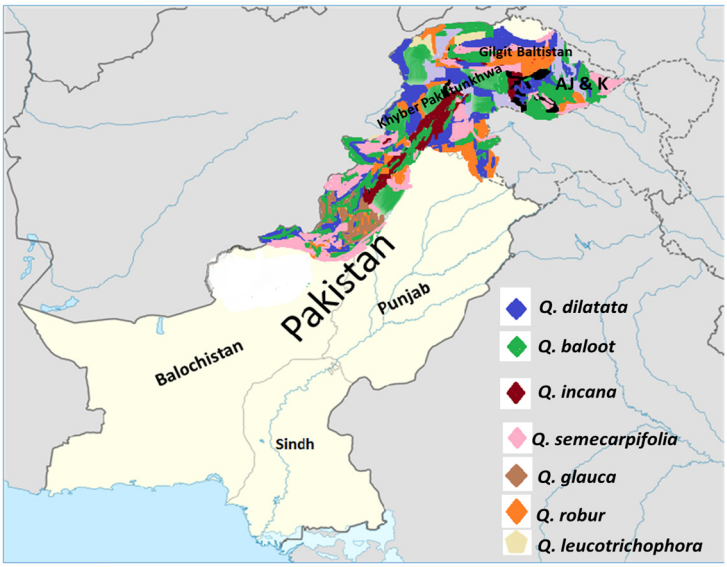

Figure 3. Map of Pakistan representing the localities of *Quercus* spp.

In more detail, in Khyber Pakhtunkhwa province, the major *Quercus* forests (Sheshikoh, Qalagay, Lalko, Manja, Sarbala, etc.) can be found in the Malakand Division (Swat, Dir lower and upper, Chitral, and Kohistan) and Hazara Division (Balakot, Sangar, and Kaghan), which form Pakistan's basic forests: tropical dry deciduous forest, dry subtropical broad-leaved forests, subtropical pine forest, Himalayan moist temperate forests, Himalayan dry temperate forests, and subalpine forest, etc. [16,37]. Similarly, Tirah, Kurram Agency, Murree Hills, and Azad Kashmir are among the locations where *Q. incana* can be found [15,16,38]. It can also be found in the Swabi district of Khyber Pakhtunkhwa province [14,16,17,19,38]. However, *Quercus* spp. are not represented in the provinces of Balochistan, Sindh, and Punjab (Figure 3).

3. Traditional Uses of *Quercus* spp. in Pakistan

3.1. Medicinal Uses

Different parts of the *Quercus* trees are used medicinally, and their identified health benefits are numerous and diverse [21]. To alleviate slight inflammatory diseases, the liquid extracted from *Q. dilatata* and *Q. incana* leaf buds can be taken internally or applied externally. The external application of bruised oak leaves to injuries and hemorrhoids helps to reduce and ease inflammation [18,22]. The bark of *Q. dilatata* and *Q. baloot* is the most commonly used in drugs because it has tonic, astringent, and antiseptic effects. It is recommended for the treatment of agues and hemorrhages, similar to other astringents [15,19,20]. The dried bark of *Q. dilatata* is employed as an anti-inflammatory agent and to treat chronic digestive problems and dysentery [25,39], as described in Table 2.

The extract of the bark from *Q. dilatata* and *Q. incana* has strong astringent properties and a bitter taste with a slightly aromatic odor when prepared as a tincture [15,17,21]. This tincture is prepared from the bark from young trees (best in the spring: April or May), which is dried in the sun before cutting. One ounce of bark is boiled in one quart of water to create a pint [18]. It can then be measured or dosed in a wineglass and used as a gargle mouthwash for chronic sore throat or locally applied to bleeding gums and piles. Hot baths are also employed to treat swelling and frostbite, and a hot compress with the bark is used to treat inflamed glands, hernias, and ulcers [18].

Those experiencing chronic diarrhea and dysentery benefit from a stronger tincture taken by the spoonful. When oak bark is finely ground and powdered, it can be inhaled to relieve nosebleeds [18,21]; it is also helpful in the early stages of consumption [38]. It helps to relieve bedsores if sprinkled on bed sheets. A pinch of powdered oak bark mixed with honey, taken in the morning, helps women experiencing menstrual problems [21,38]. Nuts ground and powder are used as a tonic for diarrhea, and a decoction of nuts and oak bark with milk is used as a medicine and as an antidote to poisonous herbs [38]. *Q. dilatata* fruit is used to treat gonorrhea and urinary tract disease; *Q. incana* fruit is used to treat enuresis and dysuria; *Q. semecarpifolia* fruit is used as a general body tonic [40]; and *Q. incana* fruit is used to cure diarrhea, digestive problems, breathing problems, and gonorrhea [26,38,41].

3.2. Consumption and Commercial Uses

The acorns of *Q. baloot* are ground into flour or roasted to make acorn coffee [14,17]. Its young leaves, buds, and twigs can be used to feed goats but are toxic to other livestock. Similarly, the young branches of *Q. incana* are used as lopping fodder for farm animals, in small quantities, and are highly preferable for goat rearing over sheep rearing. When fried, its acorns are edible. *Q. incana* is used as fodder, fuel wood, farming implements, fences, perfuse constructions, and charcoal [20,38], as well as for the manufacture of high-quality charcoal and fuel wood [38]. The nuts are inedible, but they provide the majority of the nutrition for livestock in *Q. incana* forests. The larger *Q. semecarpifolia* nuts are fit for human consumption [30,42]. Leaves, twigs, and young buds are used as farm animal fodder.

Table 2. Medicinal uses and phytochemical constituents of different organs from the Pakistani oak species.

Quercus spp.	Parts Used	Application	Chemical Constituents	References
Quercus baloot	Bark, leaves, nut	Used as anti-inflammatory agent and to treat chronic digestive problems and dysentery	___	[16,20]
	Wood	Timber, fuel	___	[14,16]
Q. dilatata	Dried bark	Used as anti-inflammatory agent and to treat chronic digestive problems and dysentery	___	[16,20,25]
	Nut	Used as a brain and sexual tonic, applied for treatment of diseases of the urinary tract	___	[16,20,21]
			Tannins, flavonoids, flavones, terpenoids, quercetin, gallic acid, syringic acid, m-coumeric acid, sinapic acid	[25,39]
Q. glauca	Wood	Widely used for timber, fuel, charcoal, building, and farming implements	___	
	leaves, nut	Used for treatment urinary tract diseases	___	
			Naringenin, gallic acid	[21,26]
Q. incana	Nut	Used to cure diarrhea, digestive and breathing problems, gonorrhea	___	[38]
	Bark	Used as antidiarrheal agent, treatment of asthma, gastrointestinal disorders, antirheumatism, antidiabetic, and antiarthritic	___	[14]
	Wood	Used as timber	___	[14,16]
			4-hydroxydecanoic acid and 4-hydroxy-3-(hydroxymethyl)pentanoic acid	[26]
Q. robur	Bark, leaves	Diarrhea	___	[21]
			Glycosides, saponins, flavonoids, and terpenoids	
Q. semecarpifolia	Nuts, fruit	Nuts are fit for human consumption; fruit is used as general body tonic	___	[21]
	Wood	Wood is used to make utensils	___	[14,21]
	Leaves, twigs, young buds	Used as fodder for animals	___	[14,21]

___ indicates that chemical constituents have been not reported.

Quercus wood is hard, stable, and attractively coarse aggregate, being widely used for timber purposes, particularly in ship making and the manufacturing of wood floors, furniture, railroad ties, casings, tool handles, and laminates. The bark contains large amounts of tannins, which are used to make leather. Locally, the hard, heavy oak wood is used for fuel, charcoal, building, and farming implements [14,41,43]. The species is a well-known fodder and feed source for livestock, particularly during the winter months when feed and forage are in short supply. In addition to fodder, it provides excellent firewood and is rarely used in building construction [14,16]. The wood of *Q. semecarpifolia* is used to make utensils. The wood of this species is still used to make the majority of the components

of traditional plows [42]. The *Q. semecarpifolia* forests are mostly intact due to their low accessibility and the reliance of local communities on the nearby temperate forests [44]. *Q. semecarpifolia* is primarily used to make plows and other agricultural implements.

In summary, the nuts of *Quercus* are edible; their leaves are used as fodder; the wood is preferred for creating agricultural instruments, particularly plows; and the wood is excellent as fuel and for snuff preparations [42,44].

4. Threats to *Quercus* Species in Pakistan

The sustainability and survival of *Quercus* spp. in Pakistan are currently threatened by both anthropogenic (deforestation) and environmental (biotic and abiotic stresses) factors [45–47]. The collective effect of these stresses has been named "decline syndrome" for Mediterranean holm oak [47], which increases the mortality and shrinkage of *Quercus* forests. *Quercus* species can compete in drought and high-temperature environments to some extent [48,49]. However, owing to climate change, including a substantial decrease in rainfall and a remarkable increase in temperature, many places where this species is found will no longer be appropriate for *Quercus* in Pakistan. Multiple insect pests and some fungi are also attacking and damaging the leaves and acorns of the *Quercus* in Pakistan. For example, new records of powdery mildew on *Quercus* trees have been reported in Pakistan. Afshan et al. [50] reported powdery mildew signs on both surfaces of *Q. baloot* tree leaves in Swat, Khyber Pakhtunkhwa, Muzaffarabad, Azad Jammu, and Kashmir. Based on morphoanatomical and molecular analyses, the authors claimed that *Cystotheca quercina* N. Ahmad, A.K. Sarbhoy, Kamal & D.K. Agarwal 2006 and *Erysiphe quercicola* S. Takam are the agents attacking *Q. baloot* [50].

In Pakistan, the regeneration of *Quercus* forests is influenced by both natural and anthropogenic factors and is hampered by environmental stress. Implementing countermeasures to the environmental impacts on oak regeneration is overlooked in Pakistan [35]. Among the environmental factors, water supply is more important for oak regeneration, particularly in the early stages [51–53]. Water is essential for the germination and emergence of new oak seedlings in forests. Other environmental factors, such as humidity, sunlight, and optimal temperature, in addition to water, play crucial roles in the growth and development of oak seedlings [51,53]. A knowledgeable human society has a strong desire to preserve such valuable and important oak forests, which necessitates proper planning and management [35]. The failure to regrow oak forests is a global issue; a decrease in oak forests detrimentally affects regional biodiversity [54,55]. The systematic approach (SDG program) of UN Agenda 21 prioritizes the conservation of these threatened and vulnerable plant species [35]. As a result, the long-term conservation and sustainable development of *Quercus* forests in the arid regions of Pakistan will require proper and systematic scientific research planning. Furthermore, drought stress is seriously affecting the *Quercus* regeneration process. Identifying and characterizing drought-resistant phenotypes is a primary concern in plant breeding, management, and conservation efforts [47] Moreover, proper molecular studies have not been conducted on the *Quercus* species found in Pakistan. As such, its inter- and intraspecific variation must be classified and its molecular mechanisms of resistance and tolerance to both biotic and abiotic stresses must be investigated.

Another threat specific to Pakistani *Quercus* is the livestock that visit the forests and eat the nuts (acorns), which causes a regeneration crisis [14,16]. The primary issue currently faced by these forests is the use of the trees as firewood for both domestic and commercial purposes. The second and third threats to oak forests are agricultural expansion and climate change, respectively. During times of scarcity, for example, *Q. glauca* is used as lopping fodder [14,41,43]. *Q. glauca* is notable in subtropical forests, which has remained easily available to the inhabitants that primarily settled in the plain [14]. Because of overexploitation, the cover and number of *Q. glauca* trees have been lost, and the soil and water conditions have changed over time, so most of the *Q. glauca* forest land has become barren rock [14,18]. Human population growth and the complete reliance of rural communities on forest trees for fuel have additionally strained local natural resources [14].

The main issues facing *Q. dilatata* are habitat destruction, lopping, and trade as high-caloric wood fuel in Pakistan [56]. However, as a snipping forage, the trees are generally kept on field boundaries, ensuring species survival. Locally, its recurrent lopping prevents successful regeneration [14]. The two main issues facing *Q. incana* are its marketability as a fuel wood and the expansion of agricultural land to all the soil that is suitable for its growth [14,41,43]. In the summer, *Q. semecarpifolia* plants are also subjected to livestock browsing, which appears to cause some damage to the forest in Pakistan [18].

5. Phytochemical Constituents Identified in *Quercus* spp. in Pakistan

Oak species are valuable sources of biologically active substances due to their widespread distribution in Pakistan. In addition, owing to the abundance of phytonutrients in *Quercus* species and the variety of folk uses, the bioactivities and toxicological effects of the compounds in this genus should be evaluated. *Quercus* possesses a wide range of compounds, including glycosides, terpenoids, flavonoids, phenolic acids, fatty acids, sterols, and tannins [16,25,39,57]. Table 2 lists the different polyphenols isolated from the *Quercus* spp. in Pakistan. In general, flavonoids (especially flavan-3-ol) and tannins are abundant in these species [21,38,41]. Naringenin and gallic acid were found in *Q. glauca* [25]. Nevertheless, chemical isolation and identification have not been thoroughly performed in Pakistani species. Thus, an in-depth study is required.

6. Conclusions and Future Research Perspectives

Quercus species are important in the configuration of forest communities, which provide timber, firewood, and food. They are found all over the world and play important roles in carbon sequestration, greening, and soil conservation. We highlighted the importance and roles of the *Quercus* spp. in the forest ecosystems of Pakistan. In particular, with respect to their ecological value and visual appeal, oaks play an important role in preserving water resource integrity. The extensive oak root system prevents soil erosion, strengthens hillsides, and allows for underground water storage. Oak is a top performer among the adaptable hardwoods and is valued by various enterprises due to its characteristics. Oaks play a crucial role in supporting natural life and maintaining local biodiversity because of their intense seed production. Many transient types of winged animals and bats perch or live in them, and they use the trees for nourishment. The leaves of the *Quercus* species are used as feed for cattle; the wood is used for furniture making, fuelwood, and charcoal production in Pakistan. Medicinally, various parts of the *Quercus* tree are used, and the health benefits of these products are diverse. In the traditional medicinal system, the fruit of *Q. dilatata* is used to treat gonorrhea and urinary tract disease, whereas the fruit of *Q. incana* is used to treat enuresis and dysuria, a nd the fruit of *Q. semecarpifolia* is used as a general body tonic [40]. *Q. incana* nuts can be used to treat diarrhea, digestive issues, breathing problems, and gonorrhea [26,38,41]. Although *Quercus* is commonly found in Pakistan, particularly in the country's northern and western regions, such as Khyber Pakhtunkhwa, Kashmir, and Gilgit Baltistan, the genus has been neglected in terms of research compared with that on other species. Continuous deforestation, fire, diseases, and pests have all contributed to a steady decline in oak forests in Pakistan. New variety breeding, pest control, and chemical and molecular research should be prioritized in future research projects in Pakistan.

Research on the genus *Quercus* is increasing, mainly from a molecular point of view. One example is a study of *Q. ilex* in Spain [47,58]. The molecular analyses started with the use of a proteomic approach, leading to the development of the first proteome reference map of *Q. ilex* leaves [59,60]. This revealed the plasticity of the organ, tree variability, and differences between developmental stages. Later, the first transcriptome and metabolome of a tissue mix were obtained [59,60]; recently, the genome was sequenced [61]. In other *Quercus* spp., the first studies have mainly focused on the genome, as it is essential for comprehending its biology and functionality. To date, a total of seven nuclear genomes [62,63] and more than twenty chloroplast genomes [29,64] have been sequenced. However, no

molecular studies have been conducted on *Quercus* spp. in Pakistan, creating a limitation to the promotion of biodiversity conservation, sustainability, and climate change adaptation.

The application of sequencing technologies, such as second-generation sequencing, will enable the discovery of large numbers of novel markers, as well as the identification of agronomically important genes in the *Quercus* species found in Pakistan. The identification of these genes will provide insight into how agronomically important characteristics are regulated, and this knowledge can be directly applied to *Quercus* species improvement in Pakistan. The genome- and transcriptome-wide identification and characterization of the gene families in *Quercus* spp. are also imperative. Furthermore, *Q. dilatata* and *Q. baloot* are morphologically mixed-type species. This may be due to natural interspecific hybridization; however, the exact reason for this remains to be elucidated.

Compared with individual analysis, an integrated analysis of different omic layers can provide scientific insight, as well as important data validation, revealing the post-transcriptional and post-translational mechanisms regulating gene expression [47]. Additionally, significant progress has been achieved using omic approaches [56,64,65]. For example, a reference transcriptome with a relatively full set of holm oak genes [64,66] and a protein database that enables proteomic analysis using the spectrometric latest technology [67] have already been reported. Additionally, the acorn and leaf metabolomes have recently been studied [68,69], but such studies have not been conducted on the *Quercus* spp. found in Pakistan. These studies will provide a valuable resource for evaluating, protecting, and effectively using the oak resources in Pakistan. Similarly, environmental factors can also affect molecular levels [70]; therefore, combining different omic technologies for obtaining a comprehensive view of the studied system is also important [71,72]. This new approach will improve our understanding of *Quercus* species biology and will allow for breeding for the selection of stress-related resilience genes or gene products as markers in breeding programs, which can ultimately aid in the conservation of the *Quercus* spp. in Pakistan.

Using nontargeted integrative multiomic analysis, we will then be able to assess and classify the transcripts, proteins, and metabolites that describe the drought response in *Quercus* species found in Pakistan, and we will identify prospective biological markers of resilience, which will be used in selecting elite, resistant, and adaptable genotypes for breeding and regeneration programs.

Oak has enormous potential as a plant used for income, health, and nutrition, in particular in northern areas of Pakistan. State policy is needed to support the regeneration, cultivation, and conservation of the existing *Quercus* spp. Using different scientific methods and techniques, the identification and selection of superior genotypes in *Quercus* spp. should be considered a major research topic in the country. Additionally, molecular studies on Pakistani oak species should be conducted to identify the most likely origins of the species and to pinpoint hubs of diversity to help lead conservation efforts. The viable populations in national parks and other protected natural areas should be quantified. The development of seed management techniques is also critical for enabling ex situ conservation.

The information obtained from DNA marker approaches has shown a high level of genetic differences and variations within the genus [72–75]. Different molecular markers have already been applied in the study of many *Quercus* species. For example, AFLP markers were applied for *Q. suber* (L.) and *Q. ilex* subsp. *rotundifolia* (Lam.) for revealing their genetic diversity [76], cpSSR markers were used to reveal genetic variation within *Q. castanea* Née genotypes [77], and EST-SSR and SSR were used for unveiling the molecular diversity in *Q. robur* and *Quercus petraea* (Matt.) Liebl. [78]. However, such important studies have not been conducted on Pakistani *Quercus* spp. The preservation of natural schemes of genetic diversity in populations and species is an essential aspect of preserving their future [79,80]. As widely known *Quercus* forest practices, the use of autochthonous specimens is suggested for the *Quercus* species population in Pakistan, although no stan-

dards exist regarding how much genetic diversity in a natural population is retained in an artificially reforested stand to ensure their survival in future generations.

The Pakistani *Quercus* spp. deserve special attention for characterization and germplasm selection for prospective use as fodder and nourishment in water-stressed regions. To identify varieties with larger leaves and fruit forms, methodical investigations and exploratory studies are required to identify viable material from diversity-rich spots, such as Khyber Pakhtunkhwa, Azad Jammu, and Kashmir. We should also identify and grow viable oak forages and food genotypes. The germplasms and varieties from different locations in Pakistan and abroad should be collected for this purpose. Moreover, documenting the genetic and sociocultural diversity of oak species is an essential step toward encouraging the long-term conservation and use of this species in Pakistan. These initiatives, which comply with the objectives of the Convention on Biological Diversity, will be incredibly useful for lower-income people, who rely on locally underused species, such as *Quercus*, for continued existence in extreme conditions, a situation exacerbated by climate change in this country. Furthermore, various chemicals and substances have been isolated from oak species; however, the modes of action of these compounds in *Quercus* plants have been poorly explored; medical trials are required, and important information on their toxic effects is insufficient. Therefore, in this particular instance, in-depth investigations are required.

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