

TAXONOMIC STUDY OF THE GENUS QUERCUS L. SECT. QUERCUS IN THE ZAGROS FORESTS OF IRAN

M. Mehrnia, T. Nejdassattari, M. Assadi & I. Mehregan

Received 30.06.2012. Accepted for publication 20.09.2012.

Mehrnia, M., Nejdassattari, T., Assadi, M. & Mehregan, I. 2013 06 30: Taxonomic study of the genus *Quercus* L. Sect. *Quercus* in the Zagros forests of Iran. –Iran. J. Bot. 19 (1): 62-74. Tehran.

The genus *Quercus* L. (Fagaceae) is one of the most diversified groups of temperate trees with more than 500 species distributed worldwide. *Quercus* section *Quercus*, the white oaks, has the greatest number of species and has the widest distribution occurring in Asia, Europe, North Africa, and North and Central America. Oak species with lobed leaves in the Zagros forests belong to the sect. *Quercus*. In previous regional taxonomic accounts, Djavanichir and Menitsky identified six and two taxa of sect. *Quercus* in Zagros forests, respectively. We studied a great number of specimens of white oaks from the Zagros forests and assigned them to previously described taxa. Then we compared them to digital images of type specimens provided by the Royal Botanic Garden Edinburgh and National Botanic Garden of Belgium. Twenty-three qualitative and quantitative characters of leaves and acorns were examined. Cluster Analysis (CA) of data showed that morphology of leaves, micro-morphology of foliar trichomes in combination with acorn morphology are valuable in species distinction. In addition, our results showed that foliar trichomes have little value in separation of taxa at species level, whereas leaf shape proved to be a better tool for discrimination of species. According to the observations and our findings, the following taxa of white oaks with lobate leaves exist in the Zagros forests: *Quercus robur* L. subsp. *pedunculiflora* (K. Koch) Menitsky, *Q. robur* L. subsp. *robur*, *Q. petraea* subsp. *pinnatiloba* (K. Koch) Menitsky and *Q. infectoria* subsp. *veneris* (A. Kern.) Meikle. *Q. robur* L. subsp. *robur* and *Q. petraea* subsp. *pinnatiloba* (K. Koch) Menitsky are reported as new records for the flora of Iran.

Mohammad Mehrnia (correspondence <m_mehrnia2004@yahoo.com>), Taher Nejdassattari and Iraj Mehregan, Department of Biology, Science and Research Branch, Islamic Azad University, Tehran, Iran.-Mostafa Assadi, Research Institute of Forests and Rangelands, P. O. Box 13185-116, Tehran, Iran.

Key words. Iran, Zagros forests, Kurdistan, Fagaceae, *Quercus*, Oaks, White Oaks, new records, SEM.

جنس بلوط دارای حدود ۵۰۰ گونه در سراسر جهان می‌باشد. گروه بلوط‌های با برگ لوب‌دار دارای بیشترین گونه نسبت به سایر گروه‌های این جنس می‌باشد. در این پروژه پراکنش گونه‌های بلوط با برگ لوب‌دار در رشته کوه زاگرس مورد مطالعه قرار گرفته است. جوانشیر ۶ گونه و مینسکی ۲ گونه از این گروه را برای زاگرس بیان کرده‌اند. نمونه‌ها بر اساس کارهای قبلی صورت گرفته، فلور سایر کشورها، عکس‌های دیجیتال از هرباریومهای باغ گیاهشناسی ادینبورگ، باغ گیاه‌شناسی بلژیک و انجام مطالعات مورفولوژیک موردشناسایی قرار گرفتند. در این مطالعه ۲۳ صفت کمی و کیفی برگ، کرک‌ها و پیاله مورد مطالعه قرار گرفت. آنالیز خوشه‌ای نمونه‌ها نشان داد که صفات برگ در این گروه نقش مهم و اساسی در جدا کردن گونه‌ها دارند و نقش کرک‌ها در جدا کردن گونه‌ها کم رنگ می‌باشد. بر اساس مشاهدات و یافته‌های ما چهار تاکسون زیر از این گروه در رشته کوه زاگرس حضور دارند.

Quercus robur L. subsp. *pedunculiflora* (K. Koch) Menitsky, *Q. robur* L. subsp. *robur*, *Q. petraea* subsp. *pinnatiloba* (K. Koch) Menitsky and *Q. infectoria* subsp. *veneris* (A. Kern.) Meikle.

و در نهایت دو تاکسون زیر برای اولین بار از فلور ایران گزارش می‌گردند

Quercus robur L. subsp. *robur* and *Q. petraea* subsp. *pinnatiloba* (K. Koch) Menitsky

INTRODUCTION

The genus *Quercus* L. (Fagaceae) is one of the most diversified groups of temperate trees with more than 500 species distributed worldwide (Nixon, 1993). Historically, Oaks have been an important source of fuel, fodder and building materials throughout their ranges. Other products include tannins and dyes, Oak bark and leaves were often used for tanning leather (Nixon, 1997). It is a dominant element in a great variety of ecosystems ranging from Mediterranean sclerophyllous communities to temperate deciduous forests and tropical mountainous plant communities (Axelrod, 1983). Numerous species, subspecies and varieties present a multiplicity of climatic, edaphic and photoperiodic adaptations. Numerous records of intermediate forms arise from studies of both fossilized and living species (Rushton, 1993). Hybridization among species of *Quercus* has been widely documented and even more widely suspected. An astounding number of hybrid combinations have been reported in the literature, and many of these have been given species names, either before or after their hybrid status was known (Palmer, 1948). Hybrids are known to occur in the wild only between members of the same section, and attempts at artificial crosses between species from different sections or subgenera within *Quercus* have been failed with very few exceptions (Neophytou, 2010).

When dealing with a suspected hybrid, therefore, one should first consider the possibility of intraspecific variation or environmental plasticity, and then seek parentage among sympatric members of the same section. Because of the almost infinite number of possible hybrid combinations, and the myriad names applied to them, only those that appear to be prominent either locally or in widespread areas are dealt with here (Nixon, 1997). High phenotypic variation within taxonomic units makes the species boundaries fuzzy and may lead to wrong detection of hybridization. Ecological and microclimatic adaptation, as well as phenotypic plasticity, are common in Oaks and increase intraspecific variation significantly (Valladares et al. 2002, Bruschi et al. 2003). White Oaks are represented by ca. 18 deciduous or semi deciduous species in western Eurasia with their diversity bulk lying in the southern part of the region (Denk and Grimm, 2010).

In order to elucidate species differentiation and hybridization at the population and individual level, several quantitative methods based on morphological traits have been proposed. The potential of analyses based on morphological traits has been increased with the introduction and development of multivariate analyses. Several different approaches have been used

in Oaks including principal component analysis (PCA), discriminant function analysis, cluster analysis and canonical variate analysis (Rushton, 1993; Jensen, 2003). The results of these methods are presented either numerically or graphically in terms of linear combinations of a set of original morphometric variables (Rohlf and Marcus, 1993). Leaf morphology has been the most important discriminator for these analyses. The use of multivariate analyses in oaks has been wide and has provided new insights about differentiation and hybridization (Neophytou et al. 2011). Hypotheses about the extent and directionality of genetic introgression have been raised based on these methods (Jensen et al. 1993; Curtu et al. 2007).

Morphological characters had been the main tool for taxonomic classification in the genus *Quercus* from the introduction of the modern taxonomy by Linnaeus in the 18th century until the recent preamble of molecular genetics (Neophytou, 2010). Various discriminant characters have been proposed for characterization of different taxonomic units. Several dichotomous keys based on flower, fruit and leaf morphology have been developed in order to describe species and sections within the genus. With the introduction of scanning electronic microscopy (SEM), new insights into discriminative characters between species have been achieved (Neophytou, 2010).

Although the use of morphometric traits has been valuable for taxonomists, a straightforward explanation of the results in a genetic context has been problematic. Morphological intermediates did not necessarily match genetically admixed forms and, on the contrary, genetically admixed individuals possessed pure phenotypes (Curtu et al. 2007, Viscosi et al. 2009). Moreover, the establishment of phylogenetic relationships by using only morphological traits has been challenged and is not supported by more recent results from analyses of molecular markers (Neophytou et al. 2007). The present study is part of a comprehensive revision of Iranian Oak taxa using both molecular (internal transcribed spacers ITS1 and ITS2 of the nuclear ribosomal DNA) and morphological evidence. The results from the molecular analysis will be presented in a separate paper.

The most comprehensive study of Iranian Oaks was by Djavanichir (1967). In his classification, the species concept was quite narrow and many infra-specific taxa were recognized as species. Therefore, the total number of Iranian *Quercus* taxa was 42. Menitsky's (1971) classification reduced this number to 12. Also, Panahi et al. (2012) studied Iranian Oaks. All of the Oak species of Iran fall into one subgenus *Quercus* and two sections: sect. *Quercus* and sect. *Cerris* (Menitsky, 2005). Species with lobed leaves in Zagros forests,

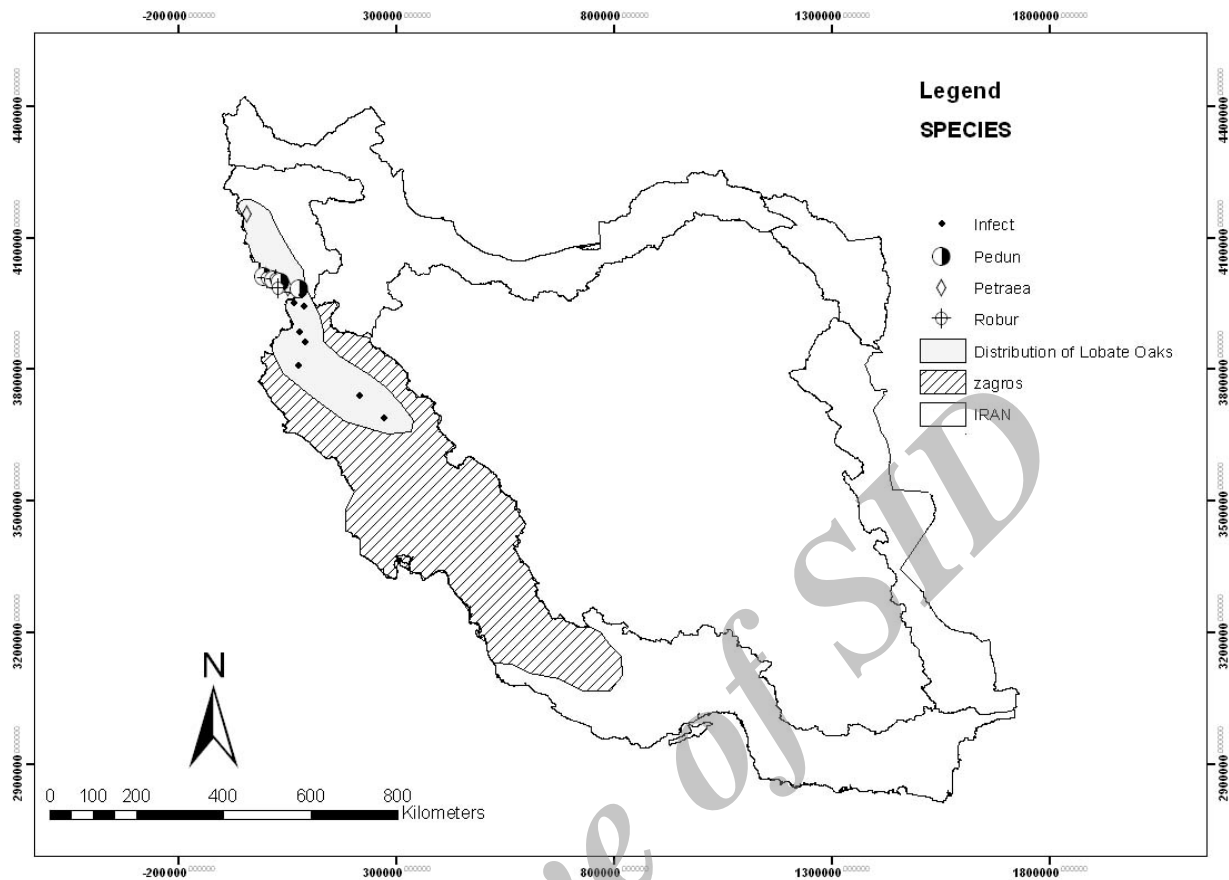


Fig. 1. Map of sampled populations of White Oaks in Zagros forest. Abbreviations, Infect (*Quercus infectoria*), Pedun (*Q. pedunculifora*), Petraea (*Q. petraea*) and Robur (*Q. robur*).

which are the object of this research, belong to the sect. *Quercus*. Djavanchir (1967) and Menitsky (1971) identified nine and four taxa of sect. *Quercus* as Iranian native Oaks, respectively.

Zagros forests cover a vast area of the Zagros mountains, their ranges stretching from Piranshahr (Western Azerbaijan Province) in the northwest of the country to the vicinity of Firoozabad (Fars Province) having an average length and width of 1,300 and 200 km (Ghazanfari et al. 2004; Erfanfard et al. 2008). The area is classified as semi-arid and covers 5 million hectares and comprises 40% of Iran's forests (Sabeti 1994, Sagheb -Talebi et al. 2005).

In the present study, morphological and micromorphological data were used to collect new information for the understanding of white Oak species in the Zagros forests of Iran. The results of this study are compared with similar studies done elsewhere. A complete survey on habitats of the recognized taxa, their distribution patterns, populations and ecological conditions were also carried out. We describe and

compare the patterns of morphological variation of the sect. *Quercus*, document zones of overlapping morphological variabilities possibly indicating hybridization in the Zagros forests, and assess the taxonomic distinctness of the species.

MATERIAL AND METHODS

The populations sampled are located in the provinces of West Azerbaijan, Kurdistan, Kermanshah and Lorestan (Fig. 1). The majority of specimens were obtained during several field trips in the Zagros forests of Iran. At least 10 specimens were studied for each taxon. Furthermore, digital images of type specimens provided by Royal Botanic Garden Edinburgh and National Botanic Garden of Belgium herbaria and general collections from the TARI & NRF (abbreviations according to Holmgren & Holmgren, 1998) were studied. Materials and collected data of some individual plant samples of all studied taxa are listed in Table 1. For determination, Les chênes de l'Iran (Djavanchir, 1967), Flora Iranica (Menitsky,

Table 1. List of selected *Quercus* species and their localities.

Species name	Localities
<i>Quercus infectoria</i>	Iran: West Azerbaijan, Sardasht, to water fall Shalmash, 1900 m, Mehrnia 12028. Iran: Kurdistan, 18 km from Marivan to Chenareh, Gumarehlnng village, Grave yard, 1400 m, Assadi 91776. Iran: Kurdistan, 7 km from Baneh to Sardasht, 1450 m, Assadi 91823. Iran: Kurdistan, Baneh, Shotormel village, 1600 m, Fattahi 8799. Iran: Kurdistan, Baneh, Khoryabad village, Kaffash 9056. Iran: Kurdistan, Sabadloe village, 1620 m, Marooft & Sabzi 1626. Iran: Kurdistan, Sanandaj, Zaleh station, 1450 m, Marooft 9397. Iran: Kurdetan, between Baneh and Sardasht, 15 km, 1550 m, Mehrnia 11908. Iran: Kurdetan, between Baneh and Sardasht, 30 km, 1800 m, Mehrnia 12030. Iran: Lorestan, Khorram abad, Kakasheraf, 1500 m, Mehrnia 12038. Iran: Lorestan, Aleshtar, Cheshmeh tala, 1350 m, Mehrnia 10808. Iran: Lorestan, Aleshtar, Cheshmeh tala, 1380 m, Mehrnia 1194.
<i>Q. petraea</i> subsp. <i>pimmatiloba</i>	Iran: West Azerbaijan, Sardasht, Mirabad village, 1292 m, Heidari 7590. Iran: West Azerbaijan, Urumiyeh, Sero, Marmishov valley, 2034 m, Heidari 7577. Iran: Kurdistana, Shalman village, Kaffash 9057. Iran: Kurdistan, Baneh, Khan pass, 1800m, Kaffash 9036. Iran: Kurdistan, Baneh to Sardasht, Zarvav village, 1450 m, Marooft & Karegar 8917. Iran: Kurdistan, Baneh, army station of Siranband, Kaffash 9048. Iran: Kurdistan, Baneh, village Zarvav, 15 km Baneh to Sardasht, 1500m, Assadi 91830.
<i>Q. robur</i> subsp. <i>pedunculiflora</i>	Iran: Kurdistan, Baneh, Shotormel village, 1600 m, Fattahi 8705 Iran: Azerbaijan, Khoy, Ghotur valley, Rahad village, Boil Apoosh village, 1420 m, Heidari 7605. Iran: Azerbaijan, Chali kuh, N.W. Selvana, 1750-2000 m, K. H. Rechingner 48929. Iran: Kurdistan, between Baneh and Saghez, between Ghorocha and Sabadlou, 8 km to Baneh, 1750-1800 m, Assadi 91787. Iran: Kurdistan, between Saghez and Baneh, Darreh Ziarat village, km 40, 1600 m, Mehrnia 12024.
<i>Q. robur</i> subsp. <i>robur</i>	Iran: West Azerbaijan, Khosro shahr, near margin of the pool Aghajan, 1340 m, Dastmalchi 43127. Iran: Azerbaijan, Sardasht, water fall Shalmash, 1800 m, Mehrnia 12017. Iran: Kurdistan, Baneh, Shalman village, Kaffash 9057. Iran: Kurdetan, Baneh, Khan pass, 1800 m, Kaffash 9059.

1971), Flora of Turkey (Hedge & Yaltirik, 1982) and Digital images of type specimens of Royal Botanic Garden Edinburgh and National Botanic Garden of Belgium herbaria were used. The voucher specimens are deposited in TARI and the herbarium of Lorestan province. Leaf samples were collected from open-grown canopy branches that showed limited morphological variations, resulting from environmental factors such as exposure and directions (Baranski 1975; Blue & Jensen 1988). Only fully expanded, undamaged

leaves without signs of disease were examined. Leaf samples were washed in 96% ethanol for 5 minutes to remove the secretions of the leaves, epicuticular waxes and dust, then each sample was placed on aluminium stubs and coated with gold using a sputter coater. Then, the specimens were studied using a LEO Scanning Electron Microscope. In the case of leaves, epidermal structures such as trichome types, number and length of the trichome rays, dimension and location of stomata were studied by SEM. The trichome ray length was

measured from the point of divergence of the ray and at the base of the trichome. Terminology used for trichome types is based on Hardin (1976, 1979a). Micro-morphological measurements were performed using Carnoy, digital measurement software (Schols et al. 2002). Quantitative and qualitative characters were evaluated for each examined taxon (Tables 2 and 3). Numerical taxonomy of 23 qualitative and quantitative morphological characters (Table 3) was also studied. To reveal species similarity, Cluster Analysis (CA) of data was performed using SPSS software ver. 18 (2009).

RESULTS AND DISCUSSION

The specimens studied were initially identified using keys from previously published works. Using different Flora keys and descriptions, we determined the following taxa of White Oaks with lobate leaves for the Zagros forests.

1. **Quercus robur** L. subsp. **pedunculiflora** (C. Koch) Menitsky, Acta Inst. Bot. Acad. Sci. Armeniae 16: 129 (1967).

Syn.: *Q. pedunculiflora* C. Koch, Linnaea 22: 324 (1849); *Q. longipes* Steven, Bull. Soc. Nat. Mosc. 30 (1): 387 (1857).

Q. longipes, based on having a glabrous peduncle, was described as a distinct species. In this paper, in agreement with previous authors, it is regarded as a synonym of *Q. robur* subsp. *pedunculiflora*.

General distribution. S. Europe, Armenia, Turkey, Transcaucasus, Caucasus, Iran. Typus from USSR E. Transcaucasus.

Distribution in Iran. W, NW and N.

2. **Q. robur** L. Sp. Pl. 996 (1753) subsp. **robur**

Syn.: *Q. haas* Kotschy, Die Eichen t. 2 (1858).

Q. haas was established based on its shorter petioles and is quite similar to *Q. robur* L. subsp. *robur*; hence, in agreement with previous authors these two taxa are treated as synonymous with each other.

General distribution. Europe, Turkey, Transcaucasus, Caucasus, Kurdistan. Typus from Europe. **Distribution in Iran.** W.

This taxon is reported as a new record for the flora of Iran.

3. **Q. petraea** L. subsp. **pinnatiloba** (K. Koch) Menitsky, Novist. Syst. Pl. Vasc. (Leningrad) 9: 112 (1972).

Syn.: *Q. pinnatiloba* C. Koch, Linnaea 22: 326 (1849); *Q. cedrorum* Kotschy, Die Eichen t. 37 (1862).

In this paper, *Q. cedrorum* in agreement with previous authors is regarded as a synonym of *Quercus petraea* subsp. *pinnatiloba*.

General distribution. S., S.E. and E. Turkey. Typus Table 2. List of the morphological characters examined for the Sect. *Quercus* in Zagros forests.

from Turkey.

Distribution in Iran. W.

This species is a new record for the flora of Iran.

4. **Q. infectoria** Oliv. subsp. **veneris** (A. Kern.) Meikle. Fl. Cyprus 2: 1479, 1897 (1985), O. Schwarz, Feddes Repert. 33: 336 (1934).

Syn.: *Q. boissieri* Reuter in Boiss., Diagn. Ser. 1 (12): 119 (1853), *Q. infectoria* Oliv. subsp. *boissieri* (Reut.) O. Schwarz, Feddes Repert. 33: 336 (1934).

Although *Q. boissieri* has priority over *Q. veneris* at the species level, the basionym subsp. *veneris* has priority at the subspecific rank. Thus the correct name for this taxon is Inclusion of *Q. veneris* A. Kern. (1904) at subspecific rank within this taxon, the name has to be *Q. infectoria* subsp. *veneris* due to its priority at that rank being established by *Q. lusitanica* Lam. subsp. *veneris* (A. Kern.) Holmboe (1914).

General distribution. Cyprus, Turkey, Kurdistan, Syria, Iran, Transcaucasus. Typus from Turkey. **Distribution in Iran.** W. and S.W.

Qualitative and quantitative characters

A. CUPULE

The cupule subtending the fruit or nut and its relationship to the fruit provides important characteristics. The morphological diversity of the cupule, scales and peduncle is valuable and useful for the classification of this group of oaks. All taxa of this group exhibit consistent annual fruit maturation patterns (fruits matured on the branches of the current year) (Fig. 2) as opposed to species in sect. *Cerris* that have been reported to exhibit both annual and biennial maturation patterns. The annual fruiting habit may have been a significant ecological factor in the successful radiation of White Oaks. In the specimens examined, cupules were solitary or in pairs, hemispherical or cyathiform, 10-18 mm in diameter, scales strongly adpressed, tuberculate at base or flat, with a brownish tip, grayish, pubescent and acorn up to 2/3 exerted. Two types of peduncles were recognized: Specimens with an elongated peduncle and specimens without or with extremely short peduncle. *Quercus petraea* subsp. *pinnatiloba* and *Q. infectoria* subsp. *veneris* have cupules with extremely short peduncle or sessile, whereas *Q. robur* subsp. *pedunculiflora* and *Q. robur* subsp. *robur* have cupules with an elongated peduncle (more than 40 mm). Usually, younger trees have narrower fruits and older trees have thicker fruits.

B. LEAF MORPHOLOGY

The investigated specimens have noticeable differences in leaf morphological characters when they form allopatric pure stands. However, intermediate trees with

Abbreviation	Description
Macromorphological characters	
LP	Length of petiole
LL	Length of lamina
TLL	Total leaf length (LL + LP)
MW	Maximal width of lamina
NL	Number of lobes
LLO	Length of lobes
WLO	Width of lobes
HMW	Height of maximal width (length of lamina from base to widest part)
PD	Petiole diameter
LWB	Leaf width at basal 1/3 of leaf
LWA	Leaf width at apical 1/3 of leaf
LLW	Length of lamina from tip to widest part (LL - HMW)
LPE	Length of peduncle
PDI	Peduncle diameter
HCU	Height of cupule
CDI	Cupule diameter
DSH	Density of stellate hairs b
Combinations of characters	
P%	Length of petiole \times 100/total leaf length
HW%	Height of maximal width \times 100/total leaf length
DW%	Length of lamina from base to widest part \times 100/total leaf length
LL/MWL	Length of lamina/maximal width of lamina
LLW/MWL	Length of lamina from base to widest part/maximal width of lamina

Table 3. The qualitative and quantitative data of morphological characters from *Quercus* ect. *Quercus* (abbreviations as in table 2).

Characters	Units	<i>Quercus axa</i>			
		<i>petraea</i>	<i>pedunculiflora</i>	<i>infectoria</i>	<i>robur</i>
Macromorphological characters					
LP	mm	20	5	16	6
LL	mm	88.5	133	69	108
TLL	mm	108.5	138	86	112
MWL	mm	40	62	35	43
NL	-	16	13	15	12
LLO	mm	6	12	2	8.4
WLO	mm	7.5	15	3	10.15
HM	mm	40	88	35	43
PD	mm	1.2	1.7	.7	.9
LWB	mm	26	47	21	32
LWA	mm	33	45	21	40
LLW	mm	40	84	36	55
LPE	mm	6	50	3	41
PDI	mm	2	1.4	1.3	2
HCU	mm	11	11	14	7
CDI	mm	13	25	13	11
DSH	-	Glabrous	Stellate	Glabrous	Glabrous
Combination of characters					
P%	%	17	3.62	18.6	3.57
HW%	%	55	63.76	42.51	68.75
DW%	%	56	60.86	44.22	63.39
LL/MWL	-	1.91	2.14	2.1	1.74
LLW/MWL	-	1.14	1.35	1.28	1.14

atypical leaf shapes and a mosaic of features in leaves are observed when species of this group are sympatric, suggesting that hybridization may explain the observed variations. However, in the regions Baneh and Chenareh continuous variation is observed in these traits, especially among individuals from mixed stands, so, most of these specimens are considered as intermediates in a sympatric zone (Fig. 3). Pure populations of *Q. petraea* subsp. *pinnatiloba* and *Q. robur* subsp. *robur* can be seen in Sardasht and Piranshar. Pure populations of *Q. robur* subsp. *pedunculiflora* can be seen in Darreh Ziarat between Saghez and Marivan. Pure populations of *Q. infectoria* can be seen in Lorestan. Leaves in pure populations possess the following features.

***Q. infectoria* subsp. *veneris*:** Leaves often overwintering until new leaves appear, very variable in size and colour, 40-70 to 10-45 mm, coriaceous, ovate to narrowly oblong, rounded or cuneate at base, margins often undulate with 4-8 crenate to serrate lobes, or entire; petiole 15-25 mm long. Usually younger leaves have smooth margins and adult leaves become toothed at the margin.

***Q. robur*:** Leaves sessile and auriculate or stalked, with 5-8 lobes, irregularly rounded, deeply lobed, occasionally with secondary lobes, indumentum of dendroid sessile hairs, \pm dense beneath or occasionally sparse, glabrous above or with some stellate hairs, rarely glabrous on both surfaces. Between the subspecies they also differ in some other traits such as follows. In *Quercus robur* subsp. *pedunculiflora*, leaves have a distinct petiole, a narrow sinus, usually with secondary lobes and tomentose, whereas in *Q. robur* L. subsp. *robur*, leaves are subsessile, sinus is broad and they are usually glabrous.

***Q. petraea* subsp. *pinnatiloba*:** petiole 15-30 mm long; leaves \pm glabrous, with 5-10 deep lobes, almost regular, without secondary lobes, intercalary veins absent. It is distinguished from the other taxa by having deep lobes, which are narrow and almost parallel.

C. STOMATA

All specimens investigated lacked subsidiary cells, i.e. they had anomocytic stomata. The shape of the stomata did not show significant differences between the species. All taxa have elliptical stomata. In all taxa, the length/width ratios of pores were about 2.5.

D. SEM MICROGRAPHS

SEM investigations of the leaf epidermis showed that the adaxial surface of leaves are mostly smooth and glabrous or sparsely pubescent, contained only solitary non glandular type of trichomes. They were single, erect or appressed, characterized by thin walls and variable length. These trichomes were situated only on the main vein. Unlike adaxial surface, trichomes

loosely arranged and distributed over the entire lamina of abaxial surface. Our findings based on the material examined can be summarized as follows (Fig. 4). The taxa differ from each other by density of trichomes, *Quercus infectoria* subsp. *veneris* were glabrous or very sparsely pilose, *Q. petraea* subsp. *pinnatiloba* and *Q. robur* subsp. *robur* have loosely arranged trichomes and *Q. robur* subsp. *pedunculiflora* which commonly has pubescent leaves has trichomes that are somewhat dense. Trichome types in all examined taxa were similar. Three types were identified, solitary non glandular, fasciculate stipitate and atypical stellate type with few arms. The trichomes are confined to the abaxial leaf surface. We have identified mean length of arms of trichomes in the examined taxa as follows: *Q. infectoria* subsp. *veneris* = 182 μ m, *Q. robur* subsp. *pedunculiflora* = 432 μ m, *Q. robur* subsp. *robur* = 110 μ m and *Q. petraea* subsp. *pinnatiloba* = 569 μ m.

E. DISTRIBUTION

The Oak species investigated here are widely distributed in western Iran and often co-occur. In general, *Q. infectoria* subsp. *veneris* has a wider distribution, can be found in vast areas of Zagros forests, and is widely distributed in West Azerbaijan, Kurdistan, Kermanshah and Lorestan provinces. Pure populations of *Q. infectoria* subsp. *veneris* are distributed to the south of the Zagros (Fig. 3). Therefore, *Q. infectoria* subsp. *veneris* is more tolerant to summer dry conditions, whereas the other three taxa in this group are found in Kurdistan and West Azerbaijan due to specific ecological needs. *Quercus robur* and *Q. petraea* were sympatric in Baneh-Sardasht region. In overlapping zone, the ecological variables were at intermediate values and species were mixed tree by tree, producing many morphologically intermediate forms between pure parental species. In such intermediate habitats, atypical leaf shapes are observed which extend the limits of taxonomically diagnostic characters, so the boundary between the species is not clearly distinct. Outside of the contact zones, in West Azerbaijan (Sardasht-Peiranshahr) and South of the Kurdistan (Marivan-Saghez), they occur as pure populations. These species have noticeable differences in several morphological characters when they form allopatric pure stands and it is rare to find intermediate trees outside of the contact zones. At the Sardasht toward Peiranshahr region, leaves have a long petiole, the maximum width is at the middle of the lamina, fruits are shortly pedunculate and pilosity is absent or loose, very short on all parts. This region is composed of *Q. petraea* subsp. *pinnatiloba* trees. At Marivan-Saghez region, the leaves are shortly petiolated, with well developed auricles at the base of the lamina, the maximum width of leaves is located in

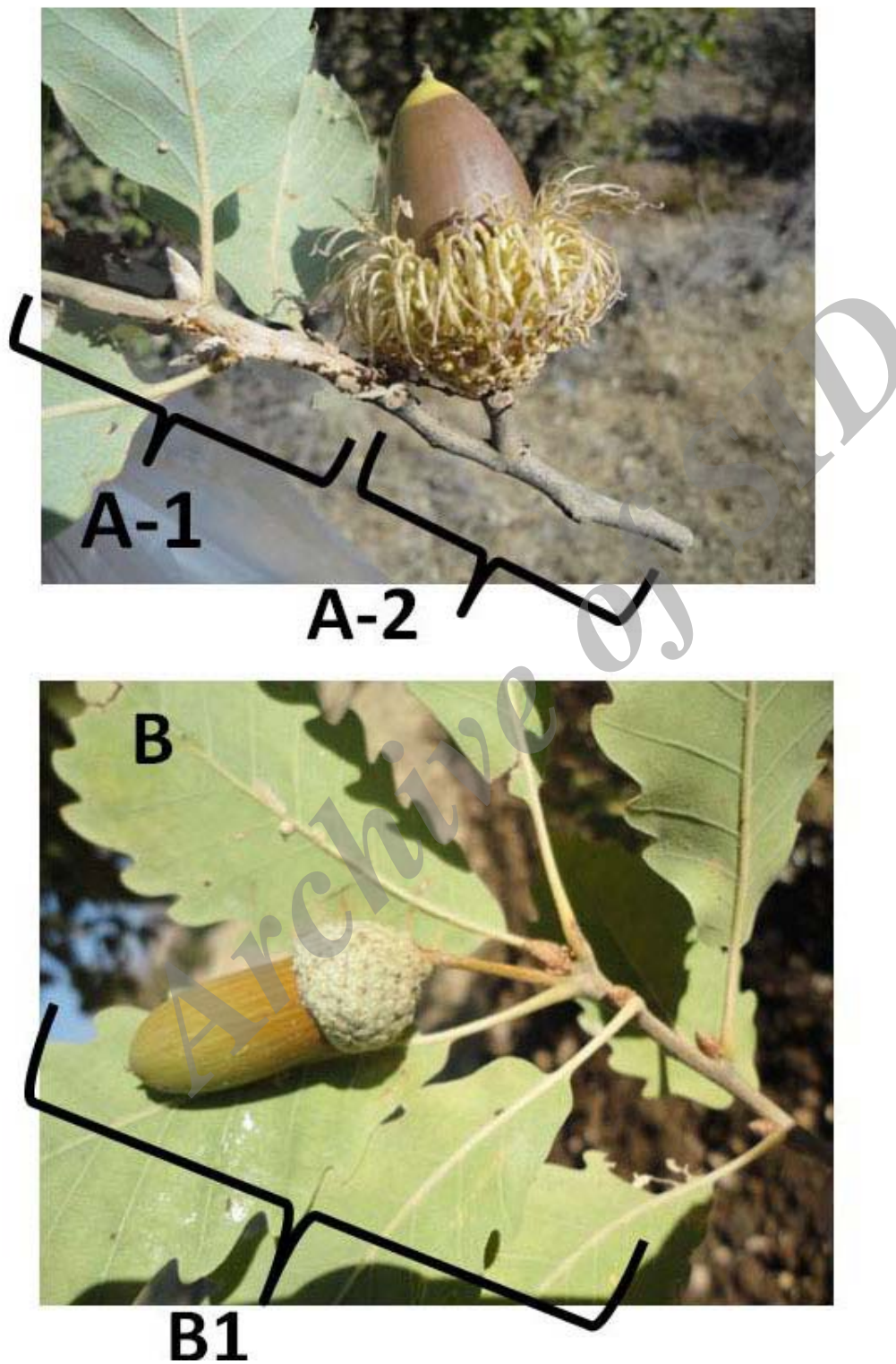


Fig. 2. A Comparison between annual and biennial-fruited habit. A: *Quercus brantii* (Cerroid oaks) A1: branches of the current year, A2: Fruits matured on the biennial branches. B: *Q. infectoria*(roburoid oaks), B1: Fruits matured on the branches of the current year.

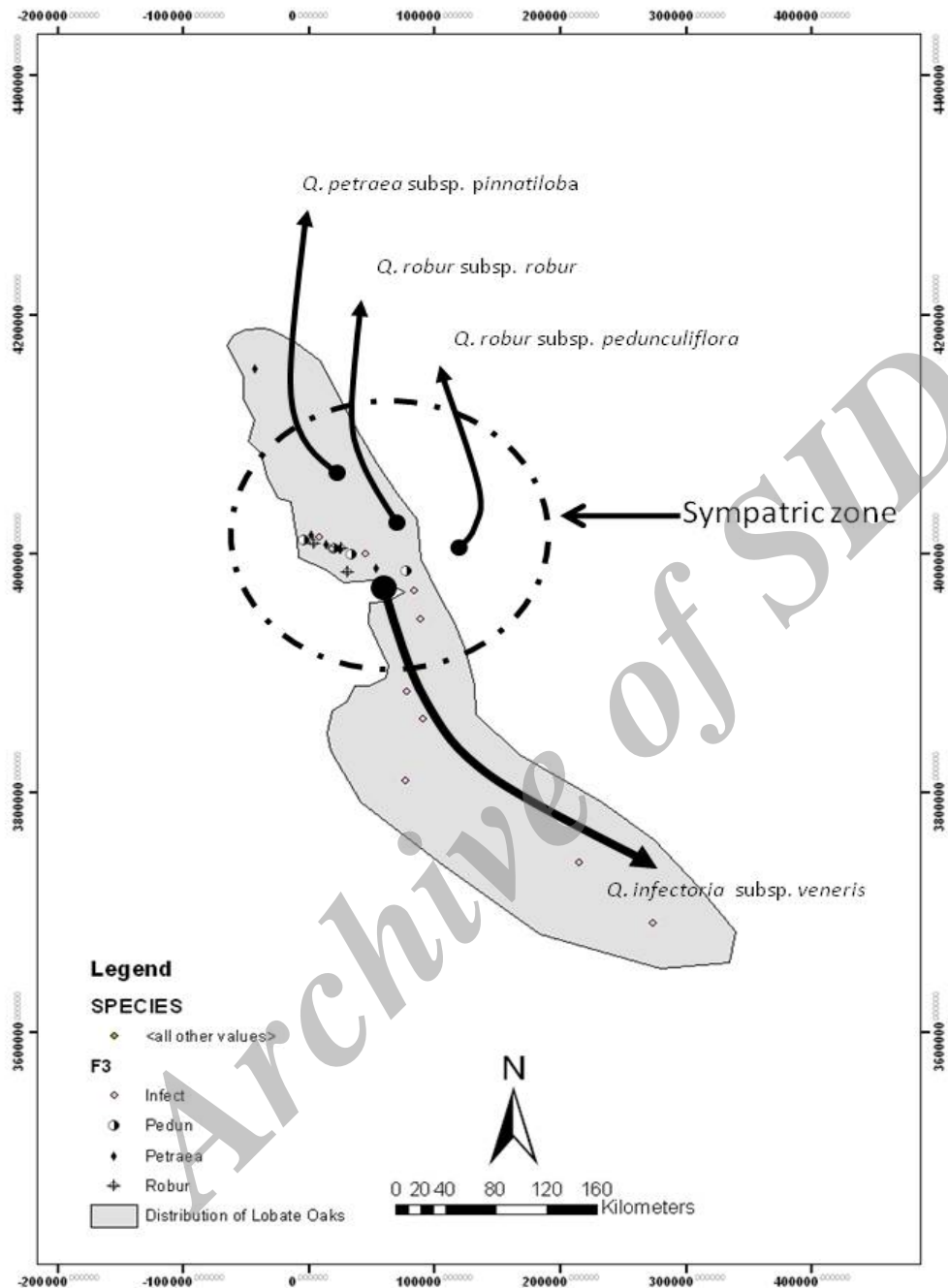


Fig. 3. Most possible routes for spread of White Oaks into Iran. Abbreviations as Fig. 1.

the upper part of the lamina, lobe sinuses have numerous intercalary veins, fruits have a long and thin peduncle and pilosity is medium to dense. This group of individuals represents the typical *Q. robur*.

F. ANALYSIS

Cluster Analysis (CA) of 23 qualitative and quantitative characters of leaf, foliar trichomes and

acorns were performed using the WARD method after standardization of quantitative data. The obtained dendrogram is represented in Fig. 5. Taxa are divided into two main groups (A, B in Fig. 5). As a result of this study, regarding controversial nomenclature used by different authors and using different Flora keys and descriptions, *Q. petraea* and *Q. robur* are totally

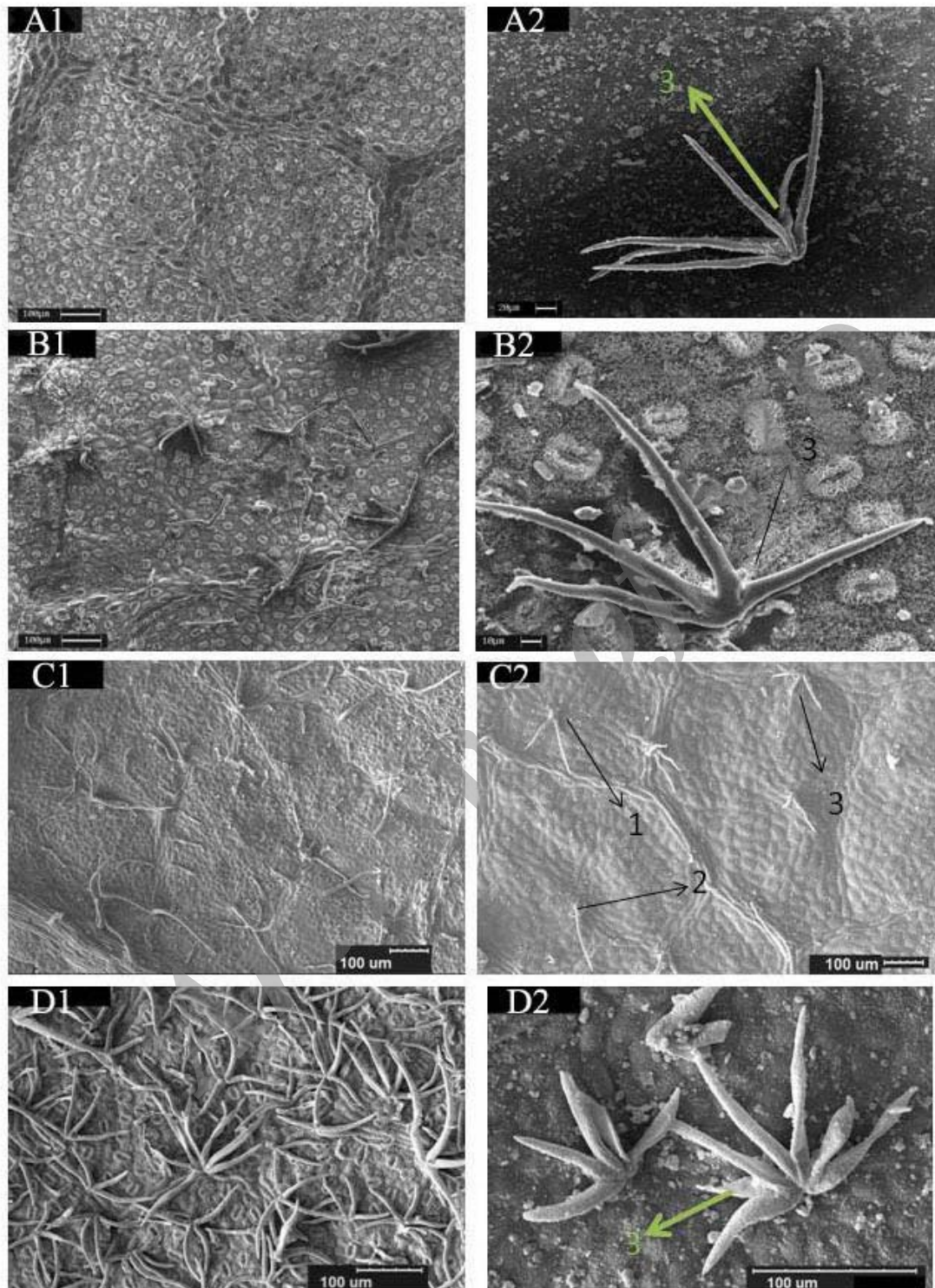


Fig. 4. Scanning electron micrographs of foliar trichomes of White Oaks in Zagros forests (general view and shape of trichomes): A= *Quercus infectoria* subsp. *veneris*, B= *Q. petraea* subsp. *pinnatiloba*, C= *Q. robur* subsp. *robur*, D= *Q. robur* subsp. *pedunculiflora*. 1,2,3 (Trichome types): 1= fasciculate stipitate, 2= solitary nonglandular, 3= atypical stellate type with few arms. Scale bar: figs. A 1, B1, B2, C1, D1, D2= 100 µm. A2 = 20 µm. C2 = 10 µm.

isolated from each other, while *Q. petraea* subsp. *pinnatiloba* and *Q. infectoria* subsp. *veneris* form a continuous group. Group B consists of *Q. robur* subsp. *pedunculiflora* and *Q. robur* subsp. *robur*. Consequently, *Q. petraea* subsp. *pinnatiloba* and *Q. infectoria* subsp. *veneris* exhibit much more intraspecific morphological variation than *Q. robur*, which appears to be more homogeneous. The best discriminate parameters are number and length of intercalary veins, length of the petiole and of the peduncle. Some classical features only appear after these variables, such as the development of an auricle at the lamina base, length of the petiole and number of intercalary veins are sufficient to separate the two species *Q. robur* and *Q. petraea* with 99% success rate. Cluster Analysis (CA) of the data showed that morphology of leaves with the combination of acorn characters are significant in separating species from each other and they do support the delimitation at species level. Therefore, the results of leaf morphological studies are as important as other taxonomic characters for distinguishing related species from each other (Table 3). Also, our results showed that trichomes of leaves cannot be used in separation of taxa at species level whereas leaf shape showed to be a better tool for separation of species.

CONCLUSION

In summary, the combination of leaf vestiture, form of the margin (entire, lobed, toothed), twig vestiture, and cupular characters constitute the majority of diagnostic features minimally required to distinguish between species. Based on the results of the present study of White Oaks in Zagros forests, an identification key is provided.

1- Leave sessile or subsessile. Peduncle elongated up to 7cm long 3 (*Q. robur*)

1- Leaves petiolate. Peduncle sessile or up to 9 mm long 2

2- Leaves entire to crenate-serrate, narrowly oblong to ovate. Scales of cupule strongly adpressed

Q. infectoria

2- Leaves deeply lobed, almost obovate. Scales of cupule strongly tuberculate at base

Q. petraea subsp. *pinnatiloba*

3- Leaves sessile, glabrous, without secondary lobes

Q. robur subsp. *robur*

3- Leaves subsessile, auriculate or stalked, almost tomentose, usually with secondary lobes

Q. robur subsp. *pedunculiflora*

ACKNOWLEDGEMENTS

We would like to thank the authorities of herbarium of

Research Institute of Forests and Rangelands and Herbarium of Natural Resources Faculty, Tehran University for permitting us to use the herbarium specimens. Thanks are due to Mrs. S. Eshghi, for preparing SEM micrographs and Dr. Chamanpeira for help with the biogeographical zonation of species using GIS and RS softwares.

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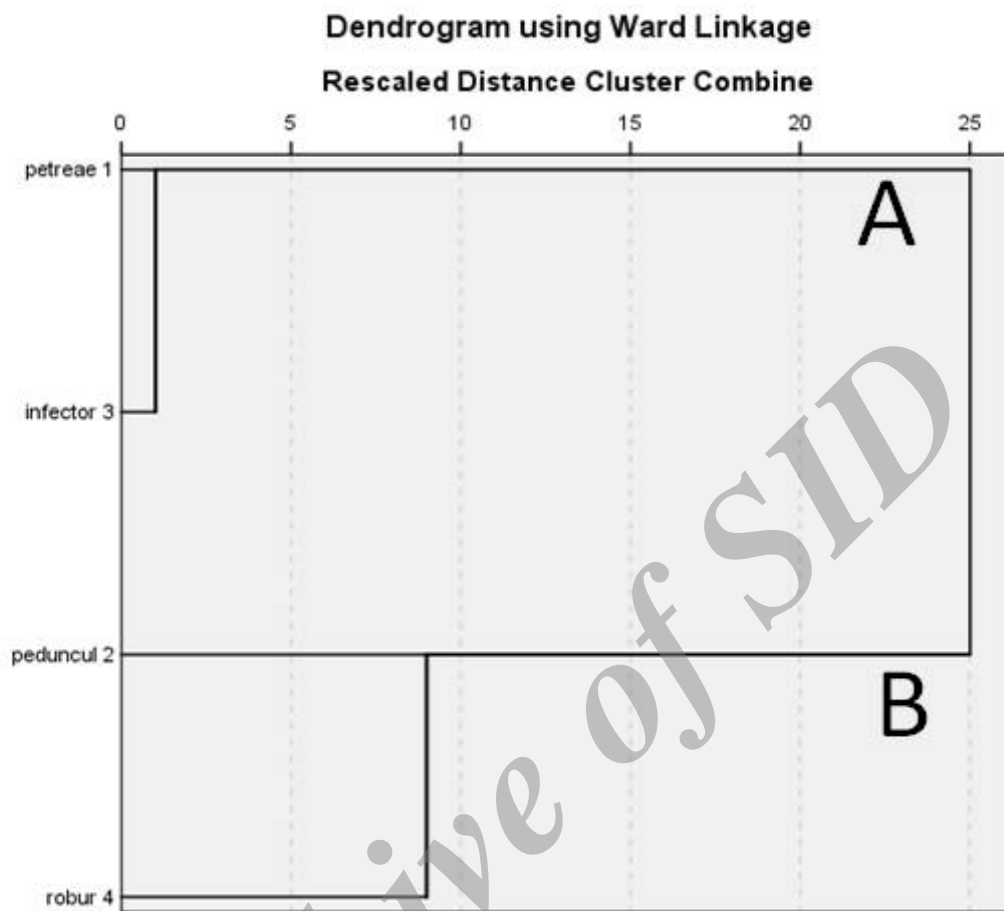


Fig. 5. Dendrogram obtained from the cluster analysis of 23 morphological characters of *Quercus* species using Ward method. petraea= *Q. petraea* subsp. *pinnatifolia*, Infector = *Quercus infectoria* subsp. *veneris*, peduncule= *Q. robur* subsp. *pedunculiflora*, robur = *Q. robur* subsp. *robur*.

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