APPLICATIONS OF ELLIPTICAL FOURIER ANALYSIS OF OAKS’ LEAVES IN TURKEY

by

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ABSTRACT

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In recent years, it is known that increasing use of morphometric methods in taxonomy, systematic, and evolutionary studies. Elliptical fouries analysis (EFA) which is one of these methods has been widely used in the investigation of leaf shapes. Oaks are classified heavily based on the leaf morphology. In this work we have studied the EFA applications of 18 *Quercus* species by analysing leaf shapes collected from 188 populations around Turkey. Principal Component Analysis (PCA) were performed to assess differentiation in leaf shapes and to compare the leaf shapes in the species and section level.

Keywords: Elliptical Fouries Analysis (EFA), Principal Component Analysis (PCA), *Quercus*, Leaf shapes, Turkey.

ÖZET

TÜRKİYE'DEKİ MEŞE YAPRAKLARININ ELİPTİK FOURİER ANALİZ UYGULAMALARI

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Son yıllarda, taksonomik, sistematik ve evrimsel araştırmalarda morfometrik yöntemlerin artarak kullanıldığı bilinmektedir. Yaprak şekillerinin incelenmesinde bu yöntemlerden biri olan EFA (Elliptical Fourier Analysis) yaygın olarak kullanılmaktadır. Meşeler ağırlıklı olarak yaprak morfolojilerine dayalı olarak sınıflandırılır. Bu çalışmada, Türkiye'nin çevresinde bulunan 188 populasyondan toplanan 18 *Quercus* türüne ait yaprakların EFA uygulamaları, yaprak şekilleri analiz edilerek çalışıldı. Yaprak şekillerindeki farklılıkları değerlendirmek ve yaprak şekillerini tür ve seksiyon düzeyinde karşılaştırmak için Temel Bileşen Analizi (PCA) uygulanmıştır.

Anahtar Kelimeler: Eliptik Furier Analizi (EFA), Temel Bileşen Analizi (PCA), *Quercus*, Yaprak şeklilleri, Türkiye.

To My Family

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ABBREVIATIONS AND SYMBOLS

EFA	Elliptical Fourier Analysis
PCA	Principal Component Analysis
URL	Uniform Resource Locat
AUC	*Q. aucheri*
BRN	*Q. brantii*
COC	*Q. coccifera*
CRR	*Q. cerris*
FRA	*Q. frainetto*
HART	*Q. hartwissiana*
ILX	*Q. ilex*
INF	*Q. infectoria*
ITH	*Q. ithaburensis*
LIB	*Q. libani*
MAC	*Q. macranthera*
PET	Q. *petraea*
PON	*Q. pontica*
PUB	*Q. pubescens*
ROB	*Q. robur*
TRJ	*Q. trojana*
VIR	*Q. virgiliana*
VUL	*Q. vulcanica*

1. INTRODUCTION

Plants play very important role on worlds ecosystem and they are one of the important components of the biodiversity. In the Nothern hemisphere, oaks are the most abundant and economically important woody plant types. Also, they creates a large part of broad-leaved forests. Because of having extensive hybridization and introgressions, systematic relationships of oak's species are not well defined yet (Curtu et al., 2007; Gugerli et al., 2007; Samuel et al., 1995; Viscosi et al., 2009b). Therefore, oaks can be considered as a complex of sympatric groups that exchange genes very often (Van Valen, 1976). Hence, oaks need to be studied to understand their diversity and evolutionary relationships. For this aim, several studies have addressed the study of morphological leaf variations in oaks by identifying morphological traits for species identification (Bruschi et al., 2000; Kremer et al., 2002; Borazan and Babac, 2003; Viscosi et al., 2009a). However, The leaf morphology of oaks is generally studied by traditional morphometric approaches by thinking as if leaf shape is linear (Dupouey and Badeau, 1993; Kremer et al., 2002; Minihan and Rushton, 1984; Wigston, 1975), because these methods are limited by the fact that they do not allow shape variation and affected by variations due to environmental factors (Ponton et al., 2004; Gottschalk, 1994). Shape variabilities can be studied as a geometric property of leaves using the geometric morphometrics. Thus, morphometrics provides a powerful tool for investigating interspecific shape differences. One of the most widely used applications for analysing the closed outlines of an object is Elliptical Fourier Analysis, EFA (Kuhl and Giardina, 1982). This analysis method is widely used to study the shape of various plant organs, such as leaves, petals, roots and seeds (Furuta et al., 1995; Iwata and Ukai, 2002; McLellan, 1993; Ohsawa et al., 1998; White et al., 1988; Yoshioka et al., 2005; Toyohara et al., 2000). For many plant families, Elliptical Fourier Analysis has become perfect and an important tool for species identification and for analysing differentiation (Andrade et al., 2010; Lexer et al., 2009; Torres and Demayo, 2008; Neto et al., 2006; Olsson et al., 2000; Viscosi et al., 2009a).

1.1. OAKS

Oaks are one of the members of the Beech family and they are one of the most important groups of trees in the world (Wyman, 1962). *Quercus* is the largest genus of the Fagaceae which has nine genera (Bakış, 2005). They are trees and shrubs having simple and alternate leaves. Their characteristics are wind-pollinated flowers, complex and strong wood, fruits which is called acorns, and ability to survive.

Oaks are found in a wide variety of habitats, and they prefer loamy and well drained soils. They have both evergreen and deciduous species. Evergreen oaks fall leaves after one to two years, however there is not simultaneously leaf loss. New leaves are formed during either the first spring growth or secondary growth which can happen when the conditions are adequate. Normal leaf loss is followed by deciduous oaks.

Oaks are very important members for the deciduous and subtropical forests and Meditteranean woodlands (Manos et al, 1999). They have ecological importance and played an important role in temperate landscapes. They provide habitat for many wildlife species. Acorns are essential for oak regeneration and are a major food source for many species of birds and mammals (Al Jassim et al., 1998; Pavlik et al., 2002; Rakic et al., 2005). Tannins, dyes and valuable nutrients are important coproducts from acorns. (Özcan, 2007). Also oaks have been used in many different ways because of their widespread distribution and largeness. For instance, Turkish oak (*Q. cerris*), sessile oak (*Q. petraea*), pubescent oak (*Q. pubescens*), and English oak (*Q. robur*) have been an important source of fuel, bait, and building materials throughout human history (Özcan, 2007). In both Europe and North America, native peoples have used their leaves, flowers, and bark to make medicine. They also maintain watershed integrity. The root system of oaks limits erosion, stabilizes slopes, and allows groundwater recharge (URL1). The wide canopies of oaks deploys the rainfall and surface erosion avoided while permitting slow saturation to the soil. Also, both oaks and other trees have ability to reduce air pollution.

The Quercus name come from the Celtic (Britton and Brown, 1970). "Quer" means "fine", and "cues" means "tree". In addition other cultures, historically the Celtic religion respect old oak trees as a focus for moral rituals. In consequence of oaks live for over 300 years, they became the literary metaphors serving as reminiscent of many historical events. Although some oaks are lived shortly, the earliest known oak lived 950 years in Switzerland.

Most species of oaks are limited to either the western or eastern regions of the continent. Human activities have played an important role in the natural range of oak species (Kleinschmit, 1993). There are some species of oaks that facing critical decline because of development pressures and modification of rangeland into housing and commercial uses and the lack of regeneration of many oak species contribute to this problem. Natural recruitment of new oak forests is limited in many areas for various reasons such as changes in vegetation, soil compaction, damage by grazing animals etc (URL1).

1.1.1. Evolution of the genus *Quercus*

The *Quercus* is the early angiosperms of the Miocene epoch (26-12 Mya) and is fairly old (Axelrod, 1983). Oaks have been divided into two lineages over time. Hybridization plays a role in the differentiation of up to 70% of the Angiosperm (Whitham et al., 1991) and also is an important factor in plant evolution triggering the differentiation of new lineages (Arnold, 1997; Rieseberg, 1997). Hybridization and introgression have been suggested to be important evolutionary forces in oaks (Burger, 1975; Van Valen, 1976). The red oaks are either lobed or unlobed and also characterized by pointed leaves. The white oak leaves are either lobed or unlobed which are round and smooth. The intermediate oaks' leaves are unlobed although some of them have teeth or spines.

A study in Europe showed that how the distribution of genetic diversity was shaped by colonisation, using historical footprints (pollen residual) and genetic fingerprints (cpDNA) (Kremer, 2002). Comparing to other angiosperms, oak is so slow evolved clade (Frascaria et al., 1993; Manos et al., 2001). The modern *Quercus* species that were evolved after the spread of genus, are limited geographically (Trelease, 1924; Axelrod, 1983). Oaks of Eurasia were limited to three areas of refuge which are Central Italy, Southern Balkan Peninsula, Southern Iberian Peninsula at the end of last glaciations (Petit et al., 2002a). Species were presumably genetically diversified among these areas of refuge. In at least 7,000 years, oaks have recolonized starting from the refuge zones to their modern zones (Petit et al., 2002a and b; Brewer et al., 2002). Then migration happened rapidly (Brewer et al., 2002). Although the southern parts of Europe has the highest diversity regions, the diversity level is important for central of European areas (Petit et al., 2002a).

Southeastern Asia and adjacent Pasific islands are the modern center of morphological diversity and this area may be the ancestral home of family according to the Kaul (1985).

Oaks comprise one of the more active groups of woody plants in terms of evolution during the Tertiary. There are now about 280 to 300 species and scores of hybrids are recognized. The great plasticity of the group is apparent in the convergence in similar leaf forms and acorn types among species belonging to different sections of the genus. Oaks proliferated in generally restricted regions, chiefly in response to increasing topographic, climatic and edaphic diversity during the middle and later Tertiary (Axelrod, 1983).

1.1.2. Biogeography of the genus *Quercus*

Quercus genus spreads all over the world especially in the Nothern Hemisphere in Asia, Africa, Europe and North America (Axelrod, 1983). Highest diversity is between 15° and 30° Nothern latitude in America and Asia. While the distribution limit of the northern reaches 62-63 latitude in Eurasia, the southern limits expands a few degrees south of the Equator in Scandinavia (Menitsky, 2005). In Europe, oaks distributes from Northern

Africa across the Mediterranean. Oaks, in central Asia, extended from China to the western border of the Himalayas, from Bhutan, Nepal up to the Northern Pakistan and Afghanistan (Negi and Naithani, 1995). In Western Asia, oaks grow in Irak and Iran on the mountains of Elbruz and Zagros, respectively. Most of European species of oaks extend at eastern limit in Caucasus where they encounter Asian species. In the excessive Asian side of the *Quercus* distribution take place in Lebanon and Palestine.

In America, the distribution of oaks extended 50° Northern latitude, and the Southern boundary is in Colombia. Only several oak species extend up to Canada. There are 34 red oak species and 49 white oak species in the United States of America (Nixon, 1993). In the western part of the United States of America, three groups were identified by Miller and Lamb (1985). These are the west Texas oaks which have nine species, the southwestern oaks which have sixteen species, and the pacific coast oaks which have eleven species (Pavlik et al., 1991). In Central America and South America consist 30 oak species.

Oak species can grow everywhere from the sea level up to 4,000 m in the Himalayas (Wang, 1961; Menitsky, 2005). The genus *Quercus* has been differentiated in a great number of species which are adapted to highly variable life swamps to deserts throughout its natural distribution. They also demonstrate a wide variety from shrubs to massive trees. The distribution range of the species can be different from local to wide intercontinental scales. *Q. rubra* L. and *Q. alba* L. in North America, and *Q. robur* L. and *Q. petreae* (Matt) Liebl. in Europe, and *Q. acutissima* Carruth and *Q. mongolica*

Fisch. ex Ledeb. in Asia are shown as typical examples of their wide distribution.

It is estimated that *Quercus* L. one of the largest genera of flowering plants, includes about 450 species (Jones, 1974), although the literature contains considerably more names and descriptions than this and variable estimates for the total number of species (Rushton, 1993).

1.1.3. Hybridization of the genus *Quercus*

Hybridization is most common in oaks and also occurs especially in species of the same or different sections. Due to the some combination of factors, *Quercus* species show high tendency to hybridize. They are all wind-pollinated and there are no strong internal barriers to prevent hybridization, when hybridization occurs between species, functional seeds and fertile hybrid offspring forms (Williams et al., 2001).

Hybridization has good effects for oak populations around the world. It has produced large populations of hybrids and evolution of new species (Conte et al., 2007). High-level introgression and regular hybridization give rise to different species in the same populations sharing up to 50% of their genetic information (Gomory and Schmidtova, 2007). This introgression and hybridization produce genetic information that does not diversify two morphologically distinct species, but diversify populations (Kelleher et al., 2005). Many hypotheses have suggested to clarify how oak species are distinct ecologically and morphologically with high-levels of gene flow.

Darwin commented the oaks are as taxonomically problematic group in the origin of species (c.f. Dumolin-Lapegue et al., 1999). In spite of

Darwin's prejudgment, the oaks have been the focus of many studies. Thus, there has been a general agreement that the level of hybridization is indeed unusual in this group (Burger, 1975; Van Valen, 1976; Rushton, 1993).

It is known that natural hybridization occurs in many plant groups (Stebbins, 1950; Lewontin and Birch, 1966; Grant, 1984). So, natural hybrids expected to have an intermediate morphology of parental species (Anderson, 1953). However, this hypothesis has been verified experimentally. Although the interspecific hybridization is common in many plant groups, the morphology of hybrids has not been studied fully. They show some differences in their morphological characters such as leaves and seeds which are used in the literature to discriminate two species (Gardiner, 1970; Ietswaart and Feij, 1989). It is very important the study of hybridization and morphology of hybrid forms in oaks to understand the evolution of them (Bacilieri et al., 1996). For instance, the sessile and the pedunculate oak can hybridize naturally. But, the morphology of their hybrids is still a subject of taxonomic studies.

Hybrid oaks have the combine of the morphological characters of their parental species (Mir et al., 2006). Oaks show extensive gene flow (Ducousso et al., 1993) and this causes the reducing differentiation between population (Kremer and Petit, 1993). Due to the wide hybridization, oaks are multi species exchanging genes (Van Valen, 1976). So, many oak species have been reported as hybrids (Castroviejo et al., 1990). For instance, the white oaks hybridize frequently (Bacilieri et al., 1996; Dodd and Afzal-Rafii, 2004; Boratynska et al., 2006; Giertych, 2006). Oaks are seen as bearing the 'cost' of hybridization, producing many hybrid offspring (Grant, 1958;

Stebbins et al., 1947; Hardin, 1975). Because of the wide distribution of *Quercus*, hybrids are occured between different species, producing many morphlogically intermediate forms between parental species (Dupouey and Badeau, 1993). Hybridization cause some difficulties in morphological and physiological definition of *Quercus* species (Kleinschmit, 1993).

There has been many debates on the species concept of European oaks (Kelleher et al., 2005). These are ranged from the difficulties of separation of species based on morphological traits (Stace, 1975) to suggestions of alternative species concepts (Van Valen, 1976). The suggested biological species concept is less appropriate for oak (Burger, 1975) due to the levels of gene exchange and hybridization within the genus (Kelleher et al., 2005).

1.1.4. Taxonomic problems of the genus *Quercus*

Since the beginning of the Linnean taxonomy, there are different ideas in the classification of genus *Quercus*. Because of this reason, many different classification methods were proposed. There are conflicts either in the characters to be used and in the species descriptions. As reported by some authors (Burger, 1975; Van Valen, 1976), there are so much variations within species due to frequent interspecific hybridization.

Because of wide distribution of oaks, taxonomists have not agreed between each other both the classification methods and criteria to be used. It is known that the most perfect classification is that of Camus (1936-1954) because of its geographic and specific cover area. The used criteria for the classification by Camus are based on characteristics of fruit and leaf. Camus has divided the genus *Quercus* into two sub-genera as *Euquercus* L. and *Cyclobalanopsis* L.. Also, *Cyclobalanopsis* has about 150 species which present in just South Asia while *Euquercus* has more common oak species. Camus has sub-divided the *Euquercus* into six different sections.

Some taxonomists proposed that the *Quercus* can be divided into two or more genera because of its heterogeneity. *Quercus* have divided into four distinct genera by some researchers such as Trelease (1924), Liu and Liao (1976), Schwarz (1936, 1964), Hjelmqvist (1948), Brett (1964), Schottky (1912). On the other hand some suggestions that *Quercus* should be join to the genus *Lithocarpus* Bl. (Bentham and Hooker, 1880; De Candolle, 1868; Corner, 1939).

Some Asian botanists have divided *Cerris* section into additional sections in contrast to Camus' classification (Zheng, 1985). Likewise, Schwarz (1964) suggested to individuate the *Coccifera* L. of the section *Cerris* with the species *Q. ilex* L. into the same section.

Quercus species is so complex and so diffucult to recognize to serve as a stable and functional method to system of nomenclature (Kleinschmit, 1993). Also, the genus *Quercus* have some taxonomic groups which are known with their complex patterns of variation, which lead to problems in the identification of taxa to at species level (Burger, 1975). However, nomenclatural and typification problems are still unresolved (Borazan and Babaç, 2003) and systematic relationship in this genus are not defined well (Samuel et al., 1995-1998), because of widespread hybridization and introgression (Hedge and Yaltirik, 1982; Sen et al., 2011; Manos et al., 1999).

So, the diversity and systematic relationship in this genus needs to be studied (Borazan and Babaç, 2003). Some species which can make hybridization with the other species in different regions of Turkey are given in Table 6 (Kasaplıgil, 1981). Many researches have concerned with the solution of the problem of species identitiy and patterns of interspecific and intraspecific differentiations (Gömöry et al., 2001).

1.1.5. The genus *Quercus* in Turkey

Turkey is one of the most important regions for *Quercus* genus according to species number and distribution of species. The genus *Quercus* is represented by 18 species in 3 sections and 24 taxa in Turkey (Hedge and Yaltirik, 1982; Yaltirik, 1984; Zielinski et al., 2006). After the study of Revision of Oaks of Turkey, number of species is decreased from 35 to current view (Kasaplıgil, 1981; Yaltirik, 1984;). Ten of them are white oak (Section *Quercus*), five of them are red oak (Section *Cerris*), remainders are evergreen oak (Section *Ilex*) (Table 1). *Quercus* species which occupy 25 percent of the forest area of Turkey including many subspecies, varieties, and natural hybrids (Ertaş, 1995; Özcan and Bayçu, 2005). So, Turkey can be considered rich in oaks.

Table 1 - Taxonomic hierarchy of genus *Quercus* and its taxa

Kingdom Plantae --- Plants
Subkingdom Tracheobionta --- Vascular plants
Division Magnoliophyta --- Angiosperms, flowering plants
Class Magnoliopsida --- Dicotyledons
Subclass Hamamelidae
Order Fagales
Family Fagaceae
Genus *Quercus* L. -- Oaks

Section *Ilex* Loudon --- **Evergreen Oaks**

- *Q. ilex* L.
- *Q. aucheri* Jaub. And Spach
- *Q. coccifera* L.

Section *Cerris* Loudon --- **Red Oaks**

- *Q. cerris* L.
    - *Q. cerris* var. *cerris*
    - *Q. cerris* var. *austriaca* (Willd.) Loudon
- *Q. ithaburensis* subsp. *Macrolepsis* (Kotschy) Hedge and Yaltirik
- *Q. brantii* Lindley
- *Q. libani* Oliver
- *Q. trojana* P. B. Webb.
    - *Q. trojana* Webb. subsp. *trojana*
    - *Q. trojana* Webb. subsp. *yaltirikii* Ziel., Petrova & D. Tomaszewski

Section *Quercus* (Endl.) Örsted --- **White Oaks**

- *Q. pontica* C. Koch
- *Q. robur* L.
    - *Q. robur* subsp. *robur*
    - *Q. robur* subsp. *pedunculiflora* (C. Koch) Menitsky
- *Q. hartwissiana* Steven
- *Q. macranthera* subsp. *syspirensis* (C. Koch) Menitsky
- *Q. frainetto* Ten.
- *Q. petraea* (Mattuschka) Liebl.
    - *Q. petraea* subsp. *petraea*
    - *Q. petraea* subsp. *iberica* (Steven and Bieb.) Krassiln.
    - *Q. petraea* subsp. *pinnatiloba* (C. Koch) Menitsky
- *Q. vulcanica* [Boiss. & Heldr. ex] Kotschy
- *Q. infectoria* Oliver
    - *Q. infectoria* subsp. *infectoria*
    - *Q. infectoria* subsp. *boissierii* (Reuter) O. Schwarz
- *Q. pubescens* Wild.
- *Q. virgiliana* Ten.

1.2. Morphometry

There are many features that used in biology for centuries. Comparing the anatomical and morphological features of organisms is one of them. The descriptors of morphological forms are used in the taxonomic classification of organism and understanding the diversity of biological life. Biology has begun the transition from an illustrative field to quantitative science, and the morphological analysis has seen a similar quantitative revolution during the early twentieth century (Bookstein, 1998). Morphological studies can be summarized as mean values and also include quantitative data type for measurable features and compared among groups (Bumpus, 1898). Quantitative rigor have advanced further by the development of statistical methods such as analysis of variance (ANOVA) (Fisher, 1935), correlation coefficient (Pearson, 1895), and principal component analysis (PCA) (Pearson, 1901; Hotelling, 1933).

Morphometrics deals with the shape variation of an object and its covariation with other variables (Bookstein, 1991; Dryden and Mardia, 1998) and also refers to the quantitative analysis of form and encompasses size and shape (Adams et al., 2004). Generally, morphometrics is the applications of multivarite statistical analysis which concerned with the quantitative variables such as height, length, and width. The analyses are generally performed on organism. They are useful in analyzing covariances between ecological factors and shape, developmental changes in form, impact of mutations on the shape, and fossil record. However, morphometrics can be used for several aims such as to detect changes in the shape, to quantify a trait of evolutionary significance, to deduce something of their morphogenesis function or evolutionary relationships. One of the main tasks of morphometics is to statistically test the hypothesis which is about the factors affecting shape. Finally, morphometrics is used to describe the shapes of the anythings.

There are two types of approaches distinguished in the morphometry:

- Traditional morphometrics,
- Geometric morphometrics.

1.2.1. Traditional morphometry

Researchers began using the full of multivariate statistical tools to describe patterns of shape variation within and among groups in the century of 20 with developing technology (Adams et al., 2004). This approach which is called traditional morphometrics (Marcus, 1990; Reyment, 1991) or multivariate morphometrics (Blackith and Reyment, 1971), consisted of multivariate statistical analyses to sets of morphlogical variables (Baltanas, 2008). Traditional morphometrics consist of multivariate statistical analyses to set measurements between points with biological and anatomical meaning to define shapes called landmarks and comprise data such as linear measurements, angles, areas, etc. and methods such as resemblance functions, ordination, classification. Also, lengths and widths of objects and distances between certain landmarks, which defined as the points of correspondence on each structure, are the general measurements. Traditional morphometric data can generally be said as measurements of size. It is developed to capture and summarize information on shape variation by sampling shape in a particular kind of way and there are also no necessary connection to the objects being analyzed (URL1). Statistical analyses usually composed of canonical variate analysis (CVA), discriminant function analysis, factor analysis, and PCA. In the most of researches allometry, and changes in shape were examined (Jolicoeur, 1963). There is a drawback of using measurements of size in the traditional morphometrics, because it is highly correlated; as a result, although many measurements, there might be few independent variables. Traditional morphometric data may be useful yet, when absolute or relative sizes are particular interest. Because of the linear distance measurement are highly correlated with size (Bookstein et al., 1985), many studies have been conducted in the developing methods for size verification, so that size-free shape variables could be extracted and patterns of shape variation elucidated (Adams et al., 2004; e.g. Sundberg, 1989; Jungers et al., 1995).

A lot of procedure suggested for size verification, but there was a dispute as to which one should be used. This situation is very important because different size verification procedure generally showed different results. Also, because of the many distances were not defined by homologous points, the homology of linear distances was difficult to define (Adams et al., 2004). Additionally, the same point of distance measures may be obtained from two different shapes. However, these measurements have one important limitation: they contain little information about the spatial distribution of shape changes across the organism (URL2). For instance, when we measure the maximum lenght and width of an objects, they may have the same lenght and width values but they are truly different in shape.

Consequently, because of the the geometric relationships among the variables was not protected, generating graphical represantations of a shape from the linear distances was not possible (Adams et al., 2004). Bradshaw (1971) considered that the ratios of measurements used either as additional descriptors, or to provide a single index of shape is important. Multivariate analysis of original measurements captured much or more variation than ratios. Thus, losing some aspects of the shape with traditional morphometry was seen.

1.2.2. Geometric morphometry

In traditional morphometrics, many analyses of set of linear angles, distances, and ratios failed to demonstrate the whole arrangement of anatomical point (Zelditch et al., 2004; Slice, 2005-2007; Baltanas, 2008). As biological researches become quantitative, modern statistics present some methods which are essential in published analysis of biological data set (Ocakoğlu et al., 2012). Modern statistical methods which can analyze whole series of observations provided a new collections of analytic tools (Richtsmeier et al., 2002).

Bookstein (1991) directed the focus from multivariate space back to the geometry of biological form (Adams et al., 2004). The concept of geometric morphometrics was first used by Corti in 1993 (Slice, 2007; Baltanas, 2008; Richtsmeier, 2002). The landmark coordinates allows the brief encoding of the entire information (Ocakoglu et al., 2012). Because of this exact storage of geometric information from data collection, the coordinate based approaches are referred to geometric morphometrics (Slice, 2007). In geometric morphometrics, shape is described as the entire geometric information which remains location, rotational effects and scale are ejected (Zelditch, 2004; Dryden and Mardia, 1998).

In the Systematic researches, the shape is most noticable features and the taxonomic categories have become one of the most used ranks (Ocakoglu et al., 2012). In geometric morphometrics, biological shape is described as the transformation of original shape. Though the morphometric methods was remarkable for analyzing biological shape, they did not have any analytical procedure yet (Thompson, 1942). Later Thompson's idea has been realized by the development of computer technologies.

The geometric data of an object which are in the forms of 2D or 3D are recorded and coordinates of studied object are more functional than traditional measurements (Rohlf and Marcus, 1993). Here, recording the homologous landmarks is very important. Other than this, studying the overall outline of an object, the data can be obtained with a sequence of digitized points along the outline (Rohlf and Marcus, 1993).

The landmarks which are the locations of discrete data collecting points, used for comparisons between characters of any objects in sytematics and they provide valuable informations about the biological forms of organisms (Dryden and Mardia, 1998).

Landmark Method

Landmark based methods begin with the collection of 2D or 3D coordinates of biologically describable points. Using these coordinates in the analysis as variables would not be appropriate while the effects of variation in orientation, position, and scale of the sample are present (Adams et al., 2004). So, the non shape variation must be eliminated. The variables become shape based and they can be used to compare the samples, after non shape variation has been ignored.

Lately, much more methods based on landmark coordinates for analyzing shape differences have become present and described in Marcus et al., (1993, 1996). Landmark consist of known three categories (Bookstein, 1991). In the type 1 of landmark, points are defined in terms of structures locally and surrounded on all sides. Type 2 landmarks which are not surrounded on all sides define in terms of local features. Type 3 landmarks are defined in terms of a point from another point. In such methods, the semilandmarks are present along a curve, but positions of semilandmarks along the curve are optional. They provide good information about curvature of specimens (Zelditch et al., 2008; Mitteroecker and Bookstein, 2008).

Outline Method

It is another method for analyzing the shape of an object. This method was used in the geometric morphometrics early. Here all points are digitized along an outline, fitted with a mathematical function. Then, curves are compared by using the coefficients of functions. Several ways are present to quantify an outline. One can use one of these methods based on outline of object and can reach success (McLellan and Endler, 1998). Earlier techniques which are "fit to a polynomial curve" (Rogers, 1982) and PCA (Glassburn, 1995), replaced by two modern procedure:

- Eigenshape analysis (Lohmann, 1983)
- Elliptical Foourier Analysis, EFA (Ferson et al., 1985)

They use hand or computer traced outlines.

These methods have their failings; susceptibility to noise is the most common and dangerous (Haines and Crampton, 2000). Moreover, researchers do not know which method is the best, because all methods working well but the problem is that several methods give different results (Rohlf, 1986).

In the eigenshape analysis, an equivalent starting point is required for each sample. This point can be source of an error for the EFA (Haines and Crampton, 2000). On the other hand, they can be applied to complex curves without the need to define a centroid; this allows removal of the effect of location, rotation, and size simpler (Haines and Crampton, 2000). Not compared points of a homologous origin are the perceived failings of outline morphometrics and it simplify complex shapes by limiting itself (Zelditch et al., 2004).

One critique about the outline based methods is the disregarding homology (Zelditch et al., 1995). An opinion corresponding to critique is that if landmark methods can be used to test biological hypothesis without homologous data, it is considered that landmark methods are inaccurate for enabling the same types of studies (MacLeod, 1999).

Elliptic Fourier Analysis (EFA)

EFA is probably considered the most useful and effective method to define and characterize the outlines (Lestrel, 1997). It is possible to test the similarities and dissimilarities among different populations with this method (Anthony, 2003). It was also proved that it is an effective tool for comparing shapes at different taxonomic and intraspecific level (Monti et al., 2001; Andrade et al., 2008-2010). Kuhl and Giardina (1982) introduced firstly the elliptic fourier method which use a chain code, closed contour, invariant to scale, translation and rotation (Eguchi and Ninomiya, 2008). Elliptic fourier method can describe any type of shape with a closed contour and this method can be generally used for measuring a biologicall shape in animals and plants (Iwata et al., 2002; Ferson et al., 1985; White et al., 1988; Diaz et al., 1989; Laurie et al., 1997; Yoshioka et al., 2004).

The EFA decomposes the closed contour shape into a series of harmonics which are defined by four fourier coefficients (Rohlf and Archie, 1984). In other words, fourier coefficients use fourier decomposition to produce harmonics which describe the positions of the points along the outline. As more harmonics are added to the mathematical function the fit to the sample curve becomes preferable (Figure 1) (URL1). The whole detailed analysis of complex structures is obtained after decomposition of outline (McLellan and Endler, 1998). Fourier analysis can generally be considered supplying the coefficients of a trigonometric function and it reproduces a sample curve (Torres et al., 2008). It is also used to provide a graphical summary of multivariate data (Andrews, 1972). The first group of practicing the Fourier method to research morphological shapes were Kaesler and

Waters (1972), and many researchers followed them (Zhan and Wang, 2012).

PCA was suggested by Rohlf and Archie (1984) to summarize the EFA (Yoshioka et al., 2004). PCA is an efficient tools for summarizing the EFA (McLellan and Endler, 1998). The application of EFA has been used in many studies and was firstly attempted by White et al., (1988), who analyzed *Betula* L. leaf shape (Yoshioka et al., 2004). Also, EFA and PCA has been used together for several plant parts; such as *Begonia* L. leaves (McLellan, 1993), buckwheat kernels (Ohsawa et al., 1998), citrus leaves (Iwata et al., 2002), radish roots (Iwata et al., 1998), soybean leaflets (Furuta et al., 1995), and yam tubers (Toyohara et al., 2000) (Yoshioka et al., 2004). In addition to these, Oide and Ninomiya (2000) used the methods for classifying soybean varieties (Neto et al., 2006). Moreover, both EFA and PCA have been used for describing the shape of different objects. Innes and Bates (1999) used these methods for demonstrating an association between genotype and morphology of shells and Chen et al., (2000) used also these methods for describing shape changes in the human mandible for male and female at different ages (cf. Neto et al., 2006).

Yoshioka et al. (2004) expressed the following view: “the using of EFA and PCA has two major advantages. First advantage is that this method can exactly detect small shape variations which is difficult for humans to detect, though it sometimes misses particular types of shape characteristics. The second advantage is that these methods can measure the shapes of objects independently of size”.

According to Polly (2012), an EFA should be summarized like that;

- Fourier harmonics used for describing the shape of outline.
- Trigonometric sines and cosines are called harmonics.
- The first harmonics describes a basic ellipse.
- As the number of harmonics increased, the outline of object is detailed.
- Shape variables can be obtained from harmonic coefficients.
- These shape variables can be used to reproduce a PCA.

Number of Harmonics

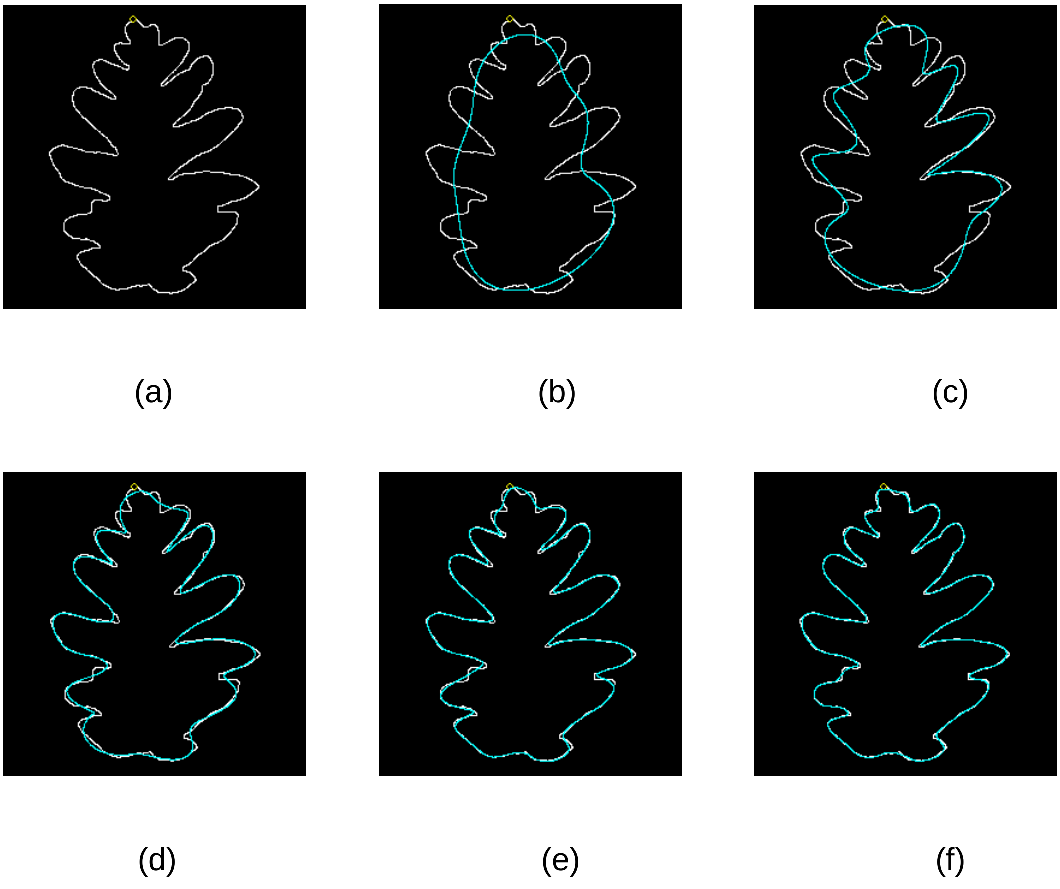


Figure 1 - Elliptic Fourier approximations; (a) Original leaf shape, (b) First five Harmonics, (c) First ten Harmonics, (d) First twenty Harmonics, (e) First thirty Harmonics, (f) First fourty Harmonics.

1.3. Aim of the Study

The oak trees in Turkey include eighteen species, with some of these form hybrids. Due to its wide hybridization, which makes taxonomy of the genus difficult, systematic relationships in this genus are not defined very well (Samuel et al., 1995). So, they are known with their problematic taxonomies. Despite all these setbacks, the morphological variability in genus *Quercus* has been studied for a long time. Also, many studies usually based on leaf morphology (Viscosi et al., 2010) because of the leaf morphology has always played an important role in plant taxonomy, particularly for identifying taxa. However, the leaf morphology of *Quercus* species is highly variable and complicated. Because of these reasons, the aim of the study is to investigate the usefulness of leaf shapes for classifying both intersectional and infrasectional of *Quercus* by using EFA.

2. MATERIALS AND METHODS

Leaves were collected immediately from the trees during journey. Second or third but some times third matured leaves with regular shapes were sampled from each branch randomly from trees. Collected leaves were placed into paper bags. Then bags which contain leaves were allowed to dry in a place without humid.

Every paper bag which represents a tree labeled with its station number, tree number, and year of collection. Samples were collected from previously known stations and stations where encountered on the road during expeditions (Table 2; Figure 2).

In our study every species were represented approximately by 5 populations, every populations by 5 trees, and every tree by 5 leaves. It was paid attention to that every species were represented by leaves from different trees of different stations. Totally 18 species, 188 populations and 1737 leaves studied from 165 stations.

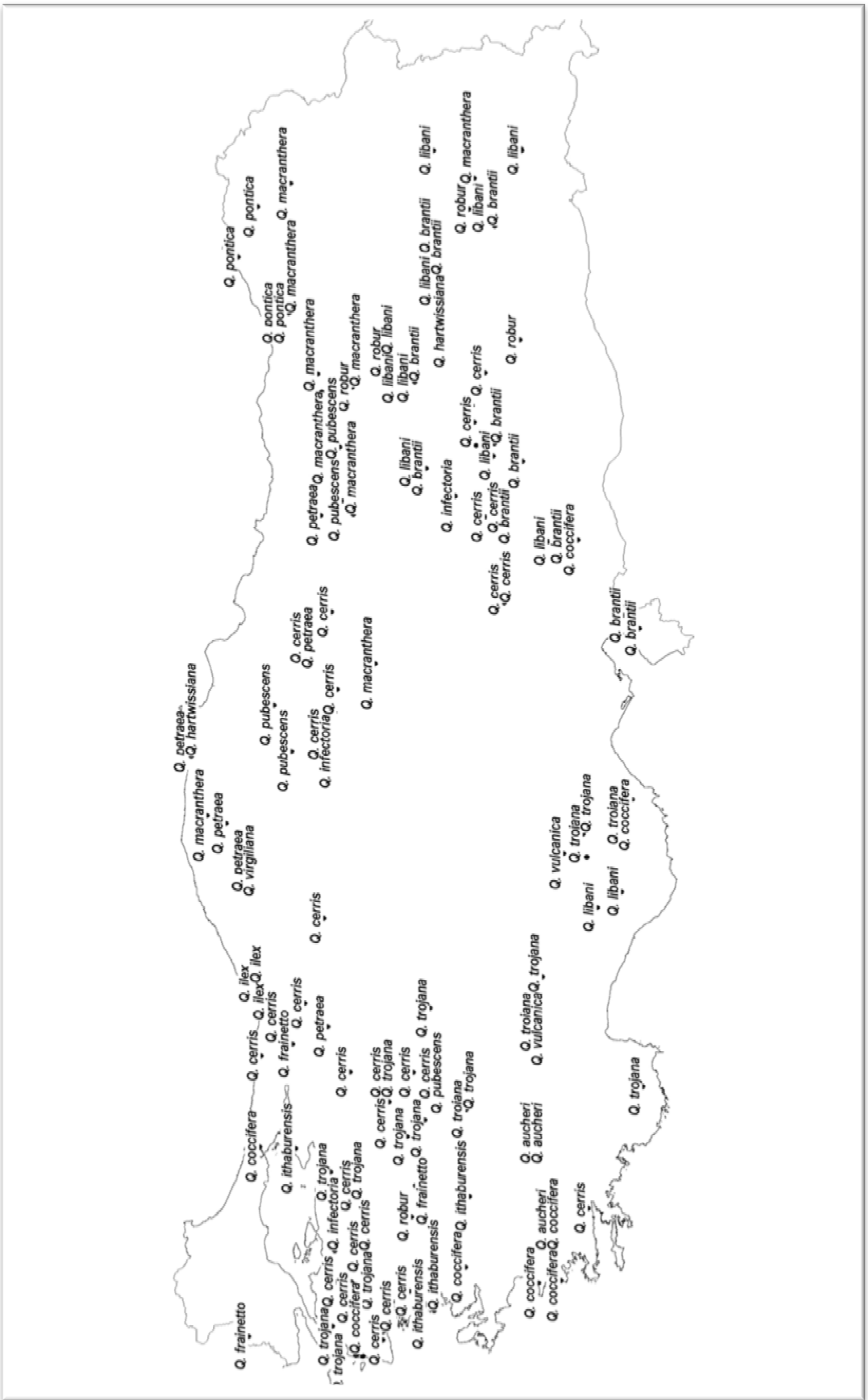
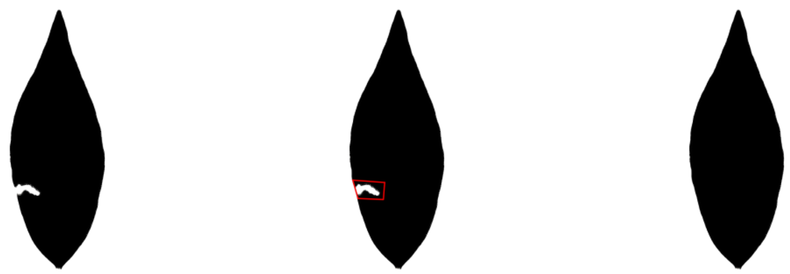


Figure 2 – Distributions and locations of the collected populations

Digital images of each leaves were scanned with EPSON Perfection 4990 Photo scanner. All of them contained 4.7 cm^2 shape scale during scanning. Then, they were converted to black and white bitmap image format with Adobe Photoshop CS6. Some scanned leaves had injuries on them (Figure 3a). Adobe Photoshop CS6 program was used to restore these injuries as follows (Figure 3a-c). Adobe Photoshop CS6 program was used to select surrounding the injured area of the leaf (Figure 3b) and used to restore this injured area (Figure 3c). Then, the adjusted image was saved. After these steps were completed, they were ready to import into the software, SHAPE (Iwata and Ukai, 2002) program for analysis.



a b c

Figure 3 – Restoration an injured leaf. An injured leaf (a) selected injured area of leaf (b) restored leaf (c).

Iwata and Ukai (2002) developed a package program which is named as SHAPE, for the quantitative evaluation of biological shapes on the basis of elliptic Fourier descriptors (Yoshioka et al., 2004). In this study, this SHAPE program package which includes some helper programs such as ChainCoder, Chc2Nef, PrinComp, and PrinPrint were used.

Recording Closed Contour of Leaves

The digital images were taken by ChainCoder as input files and then these files were passed through some procedures. The digital images were split into three colours (red, green, and blue) with 8-bit quantization. ChainCoder finally extracted the closed contours of the object and the relevant contour information was stored as chain code (Freeman, 1974). Also, the area of the object was stored.

Getting Normalized Elliptic Fourier Descriptors

Stored chain codes were taken by Chc2Nef and the normalized elliptic Fourier descriptors (EFDs) were obtained from these chain codes. The coefficients of EFDs were calculated and normalized with the procedure based on the ellipse of the first harmonic (Kuhl and Giardina, 1982). Also, the coefficients can be normalized in a different method. This method is based on the farthermost point on the contour of object from its centroid. Lastly, the normalized coefficients of the EFDs were stored in NEF file type.

Principal Component Analysis

The coefficients of the EFDs were used by PrinComp program to perform the PCA. Obtained normalized coefficients of the EFDs are not used immediatelly as shape features because of large number of coefficients and difficulties to evaluate the morphological meaning. PrinComp performs the PCA which is more powerful for getting information of the variations based on the variance and covariance matrices of the coefficients (Rohlf and Archie, 1984). After proccess of PrinComp the scores of PCA were calculated and recorded in text file type and it was used as input files for drawing PCA graphics using Minitab 16 statistical program.

Visualization of Shape Variations

Visualization of shape variation was performed for each principal component by PrinPrint programe and the coefficients of the EFDs were calculated. The visualization of shape was useful to obtain the morphological meaning of the variation.

Table 2 – Sampled populations with coordinates, altitudes, and population codes

Species name	Population code	Station number	Altitude (m)	Coordinates	
				N	E
Q. aucheri	AUC19	19	90	37°44.967	29°16.363
Q. aucheri	AUC114	114	90	37°44.967	29°16.360
Q. aucheri	AUC117	117	180	37°33.558	28°04.047
Q. coccifera	COC20	20	20	37°25.358	27°13.200
Q. coccifera	COC77	77	810	37°13.288	37°30.439
Q. coccifera	COC78	78	780	37°22.709	37°33.114
Q. coccifera	COC109	109	900	38°34.908	27°24.534
Q. coccifera	COC113	113	110	37°41.905	27°11.334
Q. coccifera	COC117	117	180	37°33.558	28°04.047
Q. coccifera	COC168	168	1140	36°41.530	33°41.529
Q. coccifera	COC169	169	1110	36°33.774	33°54.779
Q. coccifera	COC174	174	250	36°39.917	36°27.636
Q. coccifera	COC176	176	710	37°26.291	37°12.226
Q. coccifera	COC193	193	245	39°48.725	27°37.757
Q. coccifera	COC219	219	35	39°53.213	26°11.747
Q. coccifera	COC223	223	65	41.04.220	29.05.085
Q. ilex	ILX41	41	50	41°09.384	31°21.114
Q. ilex	ILX42	42	190	41°09.379	31°21.543
Q. ilex	ILX90	90	70	41°07.092	31°18.488
Q. ilex	ILX91	91	180	41°08.901	31°23.147
Q. ilex	ILX201	201	50	41°09.384	31°21.114
Q. ilex	ILX206	206	60	41°09.136	31°23.627
Q. brantii	BRN15	15	1320	38°.29.886	39°.22.599
Q. brantii	BRN17	17	825	38°.26.758	38°.49.299
Q. brantii	BRN19	19	1045	38°.13.624	38°.51.004
Q. brantii	BRN78	78	780	37°22.709	37°33.114
Q. brantii	BRN79	79	730	37°53.429	38°35.931
Q. brantii	BRN81	81	850	38°13.157	41°52.131
Q. brantii	BRN156	156	1025	39°11.540	39°42.114
Q. brantii	BRN158	158	1135	39°03.650	38°30.024
Q. brantii	BRN172	172	500	36°28.514	36°16.735
Q. brantii	BRN174	174	250	36°39.917	36°27.636
Q. brantii	BRN178	178	1110	38°08.485	37°57.471
Q. brantii	BRN283	283	1280	38°58.110	41°52.131
Q. brantii	BRN284	284	1100	38°58.110	41°34.125
Q. cerris	CRR16	16	1390	38°28.310	39°08.761
Q. cerris	CRR22	22	1655	38°20.621	37°49.601
Q. cerris	CRR25	25	700	37°05.381	28°13.875
Q. cerris	CRR73	73	1140	40°12.481	36°30.590
Q. cerris	CRR74	74	800	40°31.796	36°08.860
Q. cerris	CRR76	76	1725	38°07.976	36°49.134
Q. cerris	CRR97	97	390	39°58.940	30°07.738
Q. cerris	CRR98	98	900	39°33.745	30°07.410
Q. cerris	CRR100	100	1090	39°30.663	29°42.582
Q. cerris	CRR101	101	1110	39°12.910	30°07.410
Q. cerris	CRR102	102	1050	38°58.078	30°06.433
Q. cerris	CRR121	121	120	39°55.761	28°32.657
Q. cerris	CRR129	129	320	39°34.834	26°23.474
Q. cerris	CRR136	136	1150	40°18.825	34°48.613
Q. cerris	CRR138	138	1050	40°08.147	35°26.083
Q. cerris	CRR161	161	1600	38°20.662	39°49.637
Q. cerris	CRR178	178	1100	38°08.485	37°57.471
Q. cerris	CRR179	179	1400	38°10.889	36°47.106
Q. cerris	CRR180	180	1425	38°06.644	36°38.233
Q. cerris	CRR192	192	190	39°50.172	27°41.630
Q. cerris	CRR193	193	245	39°48.725	27°37.757
Q. cerris	CRR195	195	48	40°08.765	27°12.290
Q. cerris	CRR196	196	318	39°57.873	27°12.267
Q. cerris	CRR200	200	500	39°15.279	27°04.446
Q. cerris	CRR203	203	1280	40°17.688	32°15.692
Q. cerris	CRR251	251	50	41.03.291	30.21.001
Q. cerris	CRR260	260	650	37.08.141	28.18.215
Q. cerris	CRR266	266	340	39.34.484	26.30.271
Q. cerris	CRR269	269	640	40.31.455	31.04.985
Q. cerris	CRR271	271	260	40.49.916	30.53.400
Q. trojana	TRJ17	17	1060	39°00.487	31°00.872
Q. trojana	TRJ27	27	500	36°25.862	29°55.469
Q. trojana	TRJ31	31	1450	37°44.842	30°49.269
Q. trojana	TRJ33	33	1180	37°38.985	31°26.805
Q. trojana	TRJ98	98	900	39°33.745	30°07.410
Q. trojana	TRJ105	105	825	38°34.694	29°36.505
Q. trojana	TRJ107	107	760	39°17.287	29°13.584
Q. trojana	TRJ120	120	200	40°12.887	28°43.929
Q. trojana	TRJ121	121	120	39°55.761	28°32.657
Q. trojana	TRJ163	163	1110	37°09.275	33°25.859
Q. trojana	TRJ164	164	1120	37°09.256	33°27.188
Q. trojana	TRJ168	168	1140	36°41.530	33°41.529
Q. trojana	TRJ185	185	970	39°21.732	30°02.756
Q. trojana	TRJ186	186	1140	39°04.457	29°27.465
Q. trojana	TRJ193	193	245	39°48.725	27°37.757
Q. trojana	TRJ220	220	225	40°11.642	26°35.124
Q. trojana	TRJ265	265	825	38.34.259	29.36.303
Q. trojana	TRJ267	267	225	40.09.690	25.49.578
Q. libani	LIB14	14	1320	39°33.410	40°05.032
Q. libani	LIB18	18	1535	38°14.392	38°40.353
Q. libani	LIB24	24	990	37°34.568	37°29.213
Q. libani	LIB35	35	1600	36°59.045	32°24.603
Q. libani	LIB36	36	1490	36°41.329	32°37.556
Q. libani	LIB82	82	1640	38°19.529	42°06.577
Q. libani	LIB87	87	1490	38°58.110	41°05.685
Q. libani	LIB146	146	1350	37°54.251	42°54.905
Q. libani	LIB151	151	1310	39°33.334	40°02.531

Table 2 – Continued from previous page

Q. libani	LIB152	152	1300	39°34.332	39°57.911
Q. libani	LIB154	154	1390	39°27.480	39°53.220
Q. libani	LIB155	155	1030	39°14.059	39°45.040
Q. libani	LIB159	159	920	39°12.552	38°35.229
Q. libani	LIB283	283	1280	38°58.110	42°54.905
Q. ithaburensis	ITH38	38	540	36°36.312	33°13.983
Q. ithaburensis	ITH67	67	10	39°30.044	26°55.991
Q. ithaburensis	ITH103	103	910	38°43.288	29°43.483
Q. ithaburensis	ITH104	104	760	38°41.493	29°40.485
Q. ithaburensis	ITH105	105	825	38°34.694	29°36.505
Q. ithaburensis	ITH111	111	160	39°10.027	29°29.663
Q. ithaburensis	ITH119	119	450	38°31.950	28°23.780
Q. ithaburensis	ITH122	122	10	39°30.036	26°55.990
Q. ithaburensis	ITH123	123	140	39°25.467	26°55.435
Q. ithaburensis	ITH124	124	70	39°03.309	26°53.490
Q. ithaburensis	ITH126	126	125	39°11.881	27°17.042
Q. ithaburensis	ITH130	130	20	39°49.153	26°09.939
Q. ithaburensis	ITH198	198	105	39°10.503	26°51.387
Q. ithaburensis	ITH217	217	20	39°54.163	26°17.784
Q. ithaburensis	ITH218	218	2	39°54.428	26°10.741
Q. ithaburensis	ITH253	253	131	38.57.266	26.48.313
Q. ithaburensis	ITH259	259	580	37.08.059	28.10.388
Q. ithaburensis	ITH265	265	825	40.38.220	29.03.688
Q. infectoria	INF12	12	1050	39°18.807	38°30.273
Q. infectoria	INF16	16	1310	38°28.310	39°08.761
Q. infectoria	INF20	20	1180	38°42.144	38°06.992
Q. infectoria	INF136	136	1150	40°18.825	34°48.613
Q. infectoria	INF137	137	1065	40°09.950	35°07.235
Q. infectoria	INF145	145	1500	37°54.411	42°56.096
Q. infectoria	INF152	152	1300	39°34.332	39°57.911
Q. infectoria	INF160	160	1250	39°08.761	38°36.486
Q. infectoria	INF165	165	110	37°06.406	33°06.613
Q. infectoria	INF168	168	1140	36°41.530	33°41.529
Q. infectoria	INF190	190	350	39°45.222	27°57.616
Q. infectoria	INF194	194	65	40°09.627	27°38.230
Q. macranthera	MAC2	2	1350	39°40.452	35°47.627
Q. macranthera	MAC3	3	1560	39°56.082	37°51.828
Q. macranthera	MAC6	6	1750	40°15.866	38°50.594
Q. macranthera	MAC11	11	1715	40°43.002	40°39.432
Q. macranthera	MAC12	12	1600	40°41.977	42°27.443
Q. macranthera	MAC45	45	1180	41°42.414	33°41.099
Q. macranthera	MAC139	139	1735	39°54.439	38°28.415
Q. macranthera	MAC140	140	1535	39°57.091	39°37.896
Q. macranthera	MAC142	142	1930	40°15.547	38°50.204
Q. macranthera	MAC143	143	1650	40°19.075	39°33.553
Q. macranthera	MAC144	144	1785	40°22.386	39°48.803
Q. macranthera	MAC148	148	1675	38°28.521	42°31.668
Q. macranthera	MAC150	150	1975	39°51.962	40°37.616
Q. macranthera	MAC152	152	1300	39°34.332	39°57.911
Q. macranthera	MAC153	153	1750	39°30.537	39°52.105
Q. pubescens	PUB4	4	1360	40°04.055	38°03.320
Q. pubescens	PUB75	75	950	40°54.029	35°13.187
Q. pubescens	PUB99	99	1120	39°30.070	30°16.453
Q. pubescens	PUB102	102	1050	38°58.078	30°06.433
Q. pubescens	PUB132	132	1000	40°41.477	34°34.643
Q. pubescens	PUB133	133	1080	40°43.991	34°34.512
Q. pubescens	PUB134	134	1072	40°49.476	34°43.498
Q. pubescens	PUB135	135	800	40°45.930	34°54.536
Q. pubescens	PUB141	141	1125	40°06.071	38°47.821
Q. pubescens	PUB182	182	660	40°31.450	31°04.973
Q. petraea	PET9	9	1470	40°19.955	37°51.009
Q. petraea	PET39	39	1670	40°54.410	31°10.394
Q. petraea	PET42	42	190	41°09.379	31°21.543
Q. petraea	PET43	43	400	41°14.111	33°03.424
Q. petraea	PET44	44	120	41°22.256	33°11.333
Q. petraea	PET48	48	10	41°56.452	34°42.586
Q. petraea	PET49	49	810	41°28.879	33°34.497
Q. petraea	PET74	74	800	40°31.796	36°08.860
Q. petraea	PET149	149	1600	38°32.470	42°06.087
Q. petraea	PET193	193	245	39°48.725	27°37.757
Q. petraea	PET221	221	600	40°15.123	30°45.402
Q. vulcanica	VUL31	31	1450	37°44.842	30°49.269
Q. vulcanica	VUL162	162	1795	37°23.495	33°09.742
Q. virgiliana	VIR43	43	400	41°14.111	33°03.424
Q. robur	ROB9	9	1390	39°33.720	40°06.808
Q. robur	ROB80	80	690	37°55.536	40°17.053
Q. robur	ROB83	83	1600	38°32.470	42°06.087
Q. robur	ROB84	84	1480	38°33.442	42°05.492
Q. robur	ROB85	85	1250	38°36.866	41°56.521
Q. robur	ROB140	140	1535	39°57.091	39°37.896
Q. robur	ROB189	189	365	39°14.093	28°06.501
Q. pontica	PON10	10	1880	40°52.351	40°39.432
Q. pontica	PON62	62	1525	41°35.933	41°68.116
Q. pontica	PON63	63	1450	41°20.193	41°26.368
Q. pontica	PON66	66	1880	40°52.351	40°39.432
Q. hartwissiana	HRT46	46	180	41°53.602	34°30.442
Q. hartwissiana	HRT86	86	1480	38°56.052	41°10.062
Q. frainetto	FRA40	40	200	40°54.075	31°10.836
Q. frainetto	FRA89	89	200	40°54.075	31°10.386
Q. frainetto	FRA92	92	320	40°40.828	30°30.864
Q. frainetto	FRA95	95	910	40°05.723	29°52.621
Q. frainetto	FRA187	187	700	39°08.550	28°43.917
Q. frainetto	FRA188	188	510	39°10.978	28°32.670
Q. frainetto	FRA191	191	340	39°49.444	27°48.992
Q. frainetto	FRA208	208	60	41°12.036	29°00.825
Q. frainetto	FRA214	214	45	41°12.352	26°26.533

3. RESULTS

When the EFA results of all sections were investigated (Figure 4), although the morphometric leaf analysis results of both section *Quercus* and *Ilex* overlapped in the central area, two separate large homogeneous groups occured. Leaves which belonging to *Cerris* section greatly overlapped with groups of *Quercus* and *Ilex* sections. However, if *Cerris* section is closely examined, it is seen that the most of them fell into the Ilex section. The remaining leaves took part in *Quercus* section.

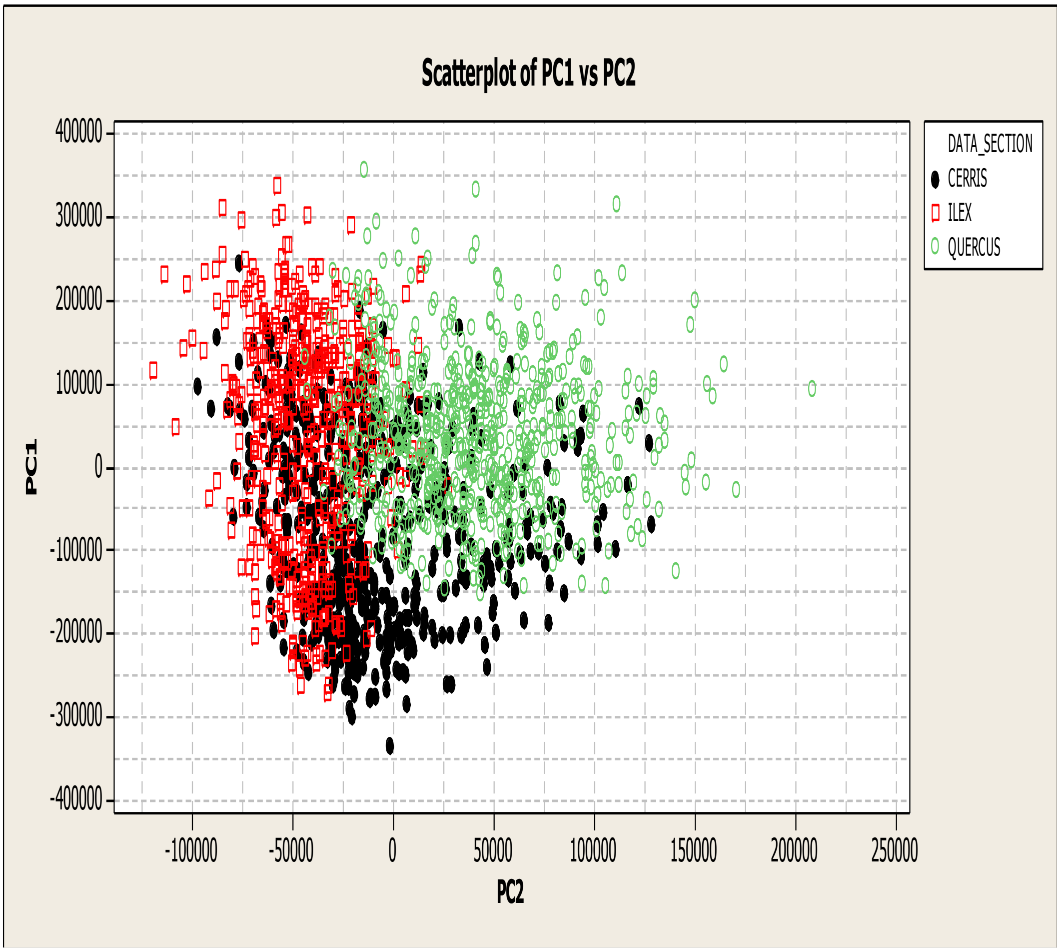


Figure 4 – EFA results of all section

When the morphometric leaf PCA results which belong to these three sections were examined in twain, the following results were obtained and it can be said that the very good results can be obtained with Fourier analysis.

***Quercus - Ilex* sections :** The leaves which belonging to these two groups created homogeneously two separate groups. However, some leaves mixed with each other in the central area (Figure 5).

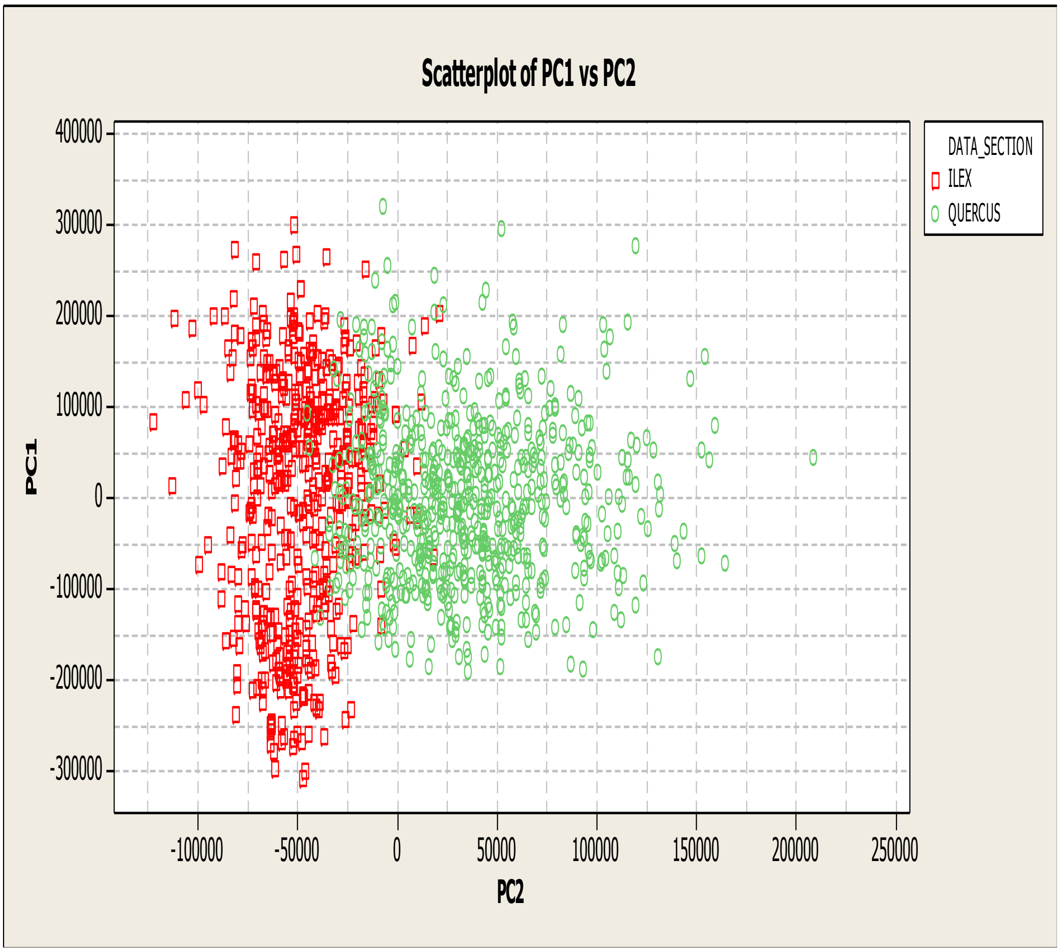


Figure 5 – EFA results of *Quercus* and *Ilex* sections

***Quercus* - *Cerris* sections :** Leaves of these two groups were overlapped with each other at a rate of less. It can be still said that they created more or less two separate groups (Figure 6).

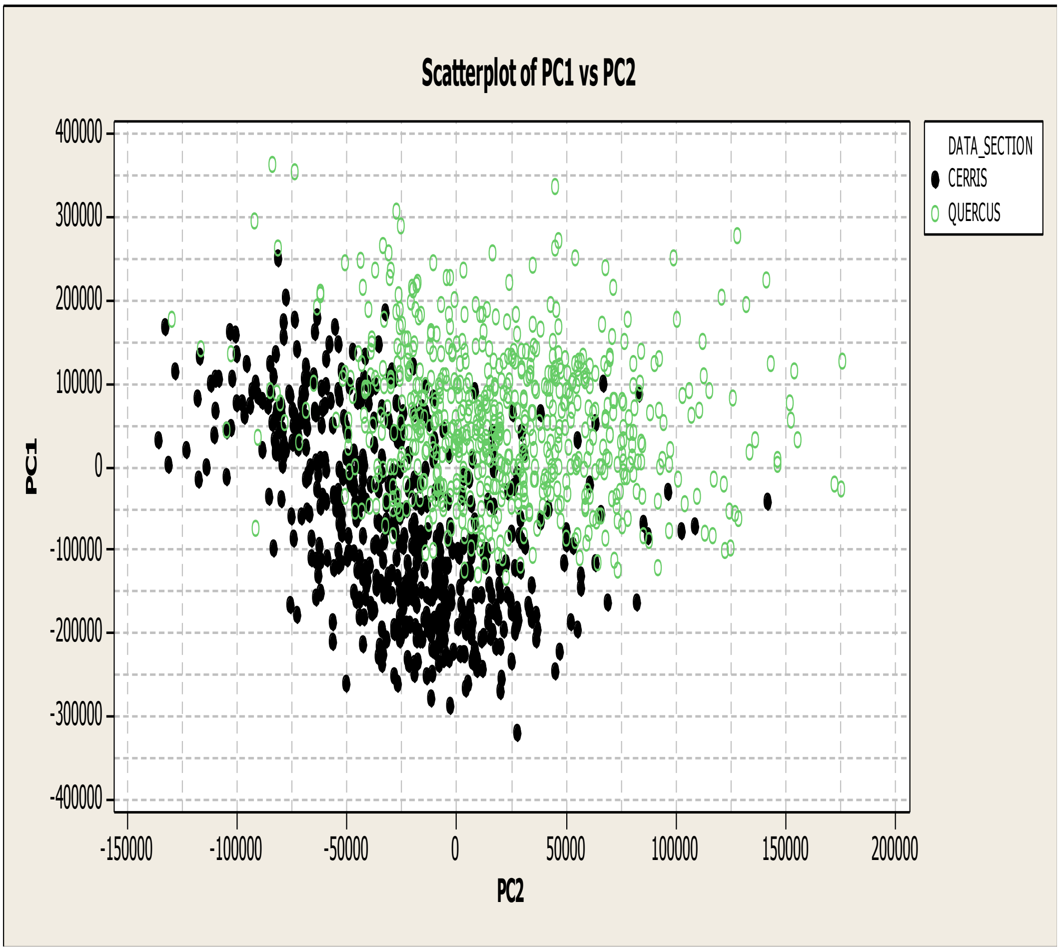


Figure 6 – EFA results of *Quercus* and *Cerris* sections

***Cerris* - *Ilex* sections :** While the leaves which belongs to *Cerris* section formed two separate groups being fairly homogenous (Figure 7), the leaves of *Ilex* section formed a quite small group. However, a few portion of the large *Cerris* section mixed with this small *Ilex* section.

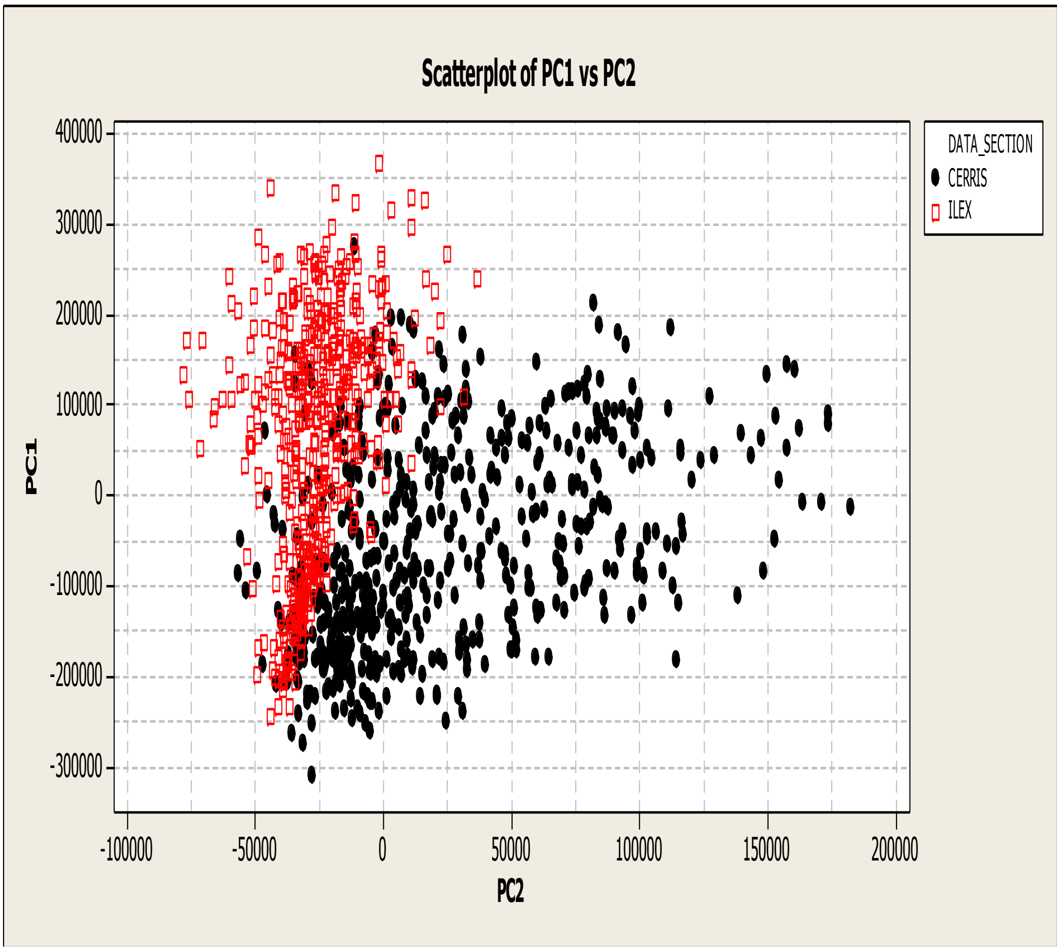


Figure 7 – EFA results of *Cerris* and *Ilex* sections

***Cerris* Section :** The EFA result showed that the leaves of *Q. brantii* and *Q. ithaburensis* approximately overlapped each other and these species were separated from other species clearly. Similarly, the leaves of *Q. libani* and *Q. trojana* gave the same result. The leaves of these taxa overlapped each other and they were separated from leaves of other taxa. On the other hand, the leaves of *Q. cerris* formed a distinct group (Figure 8).

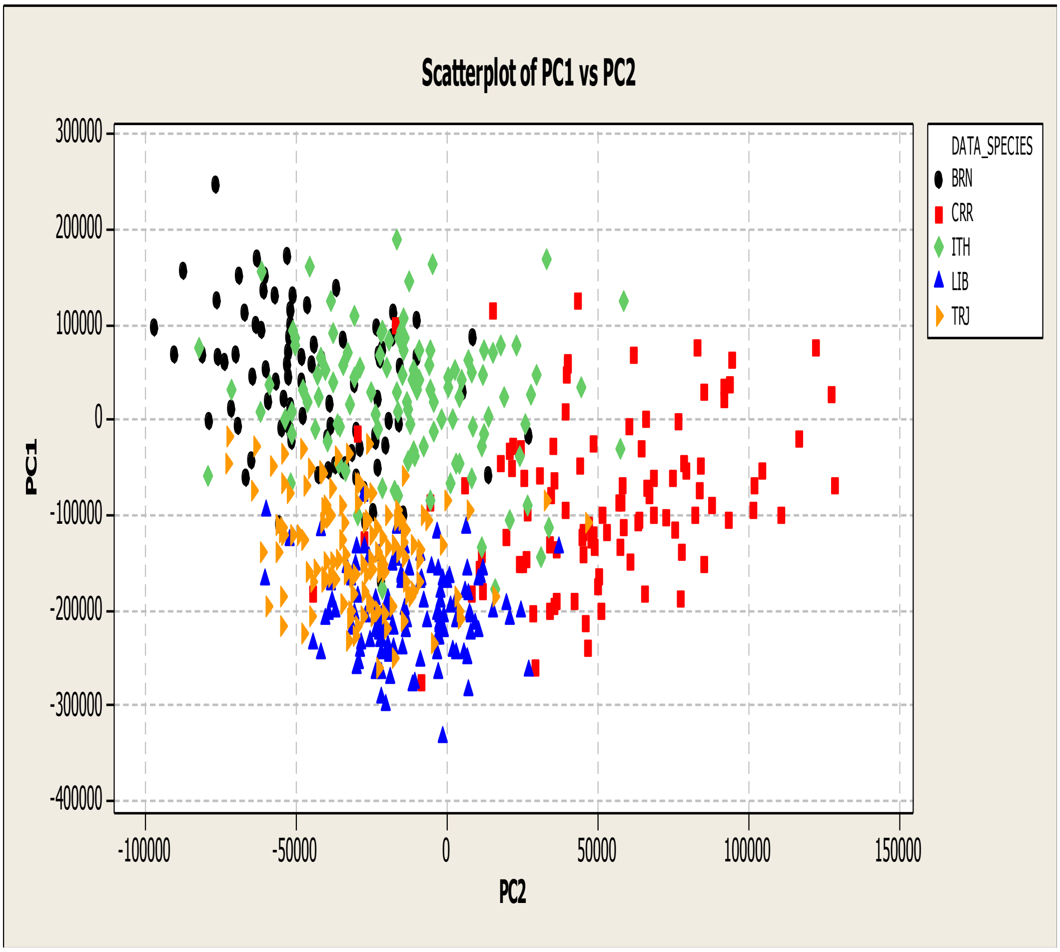


Figure 8 – EFA results of *Cerris* section

***Ilex* Section :** The leaves of taxa belonging to this section formed two large groups. The leaves of *Q. aucheri* and *Q. coccifera* overlapped each other largely. However, the leaves of *Q. ilex* were separated from those of other species clearly (Figure 9).

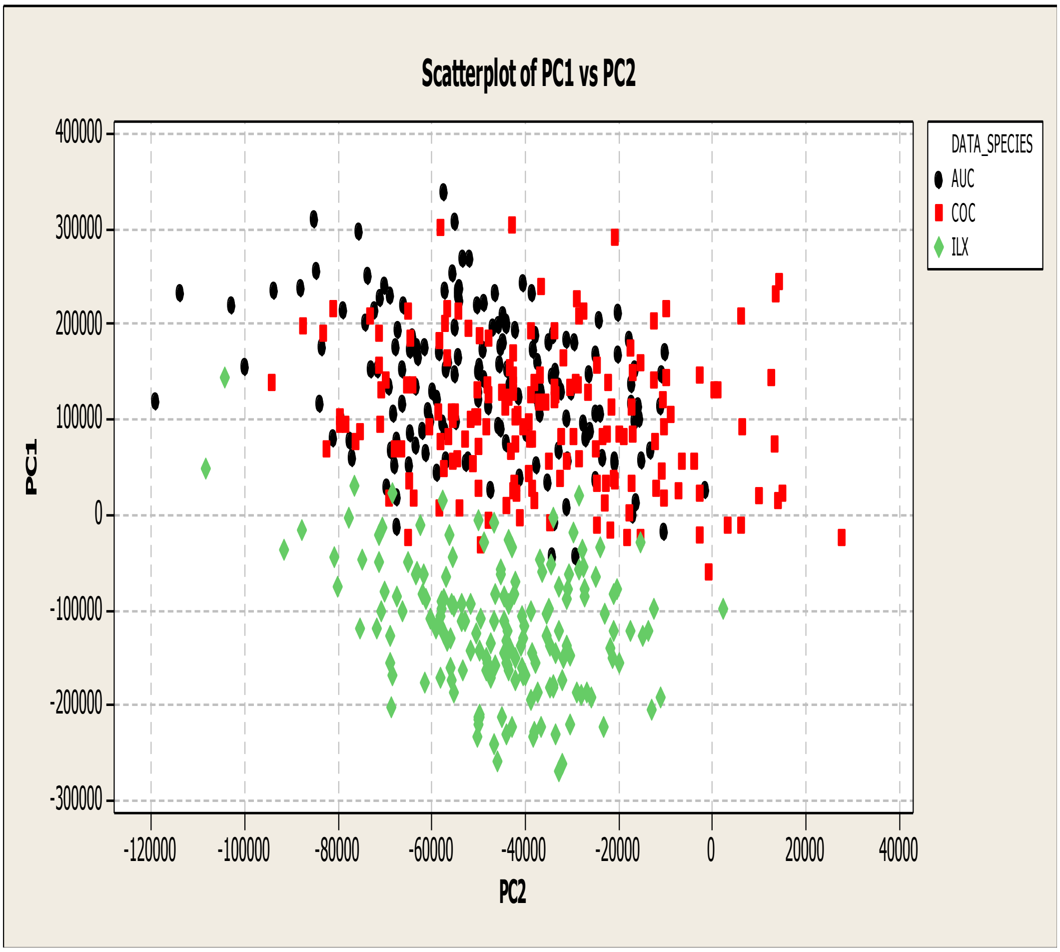


Figure 9 – EFA results of *Ilex* section

***Quercus* Section :** The leaves belonging to this section formed a very complex grouping. While the leaves of *Q. frainetto* and *Q. robur* took place at the right of the graph, the leaves of *Q. pontica* were at the left of the graph. The leaves of *Q. infectoria*, *Q. hartwissiana*, *Q. petraea, Q. pubescens*, *Q. virgiliana* overlapped each other in a very complex structure. However, The leaves of *Q. vulcanica*, *Q. pontica*, *Q. frainetto*, *Q. robur* were separated from others comperatively (Figure 10).

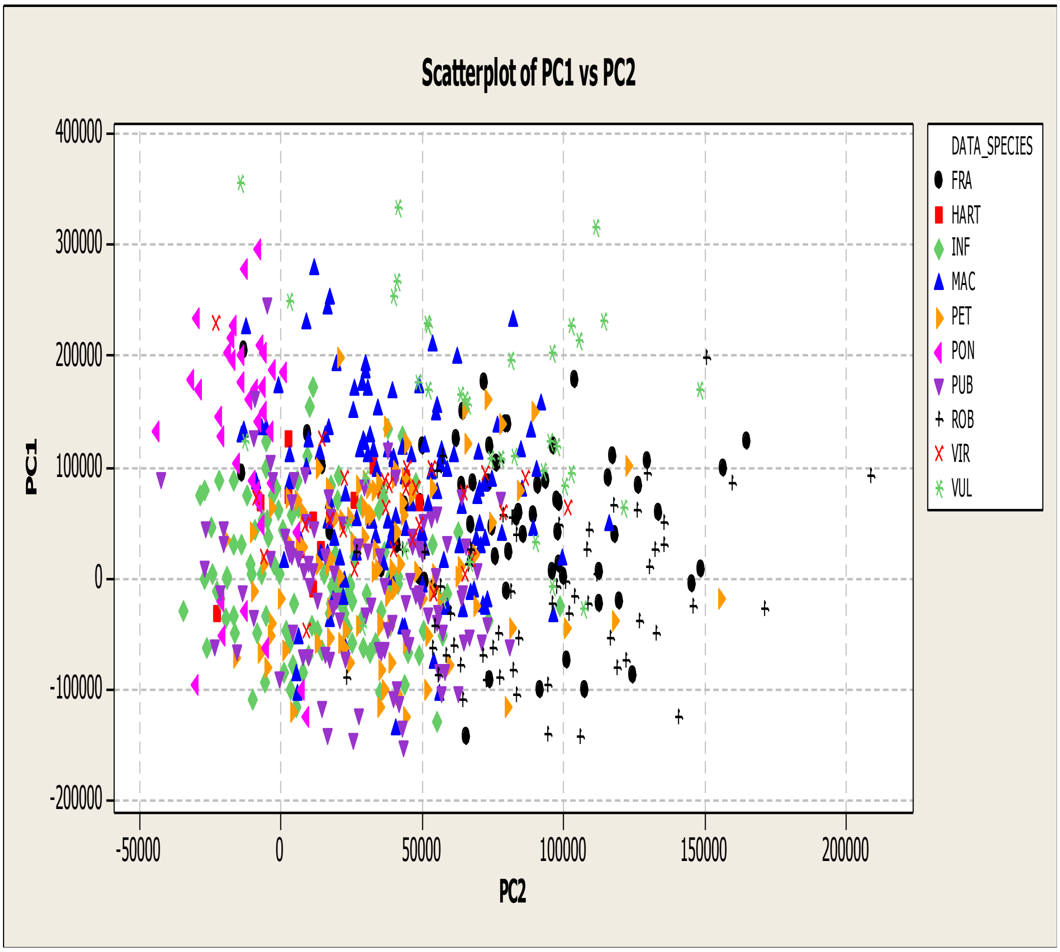


Figure 10 – EFA results of *Quercus* section

4. DISCUSSIONS

In this study, The results of EFA have shown some notable approaches. Particularly at intersection level, *Quercus* and *Ilex* sections showed comparatively two clear groups (Figure 5). However, when the species belonging to the *Cerris* section added to the analysis, this clear groups became a complicated situation. Because, the leaves of species belonging to *Cerris* section mixed with the leaves of species belonging to both *Quercus* and *Ilex* section (Figure 4). Also, remarkable results were noted in the infrasection level. For example; in the *Cerris* section, it is seen that the leaves of *Q. cerris* showed quite a large variation. Because this species show variability in their leaf lobes changing from very shallow to very deep structures. In addition, their leaf lenghts are ranging from 4-5 cm to 9-10 cm and their leaf widths do not exhibit more variation. Their leaves have usually regular lobes. Although their leaves formed rather homogenous group, the leaves which located at the ends of this group fall into the groups belonging to other four taxa (Figure 8). On the other hand, the leaves of *Q. brantii* showed variation not as much as the leaves of *Q. cerris*. Because, the leaves of individuals belonging to this species have quite irregular lobes. Their leaf lenghts also show quite variation. However, they showed very little overlap with the leaves of individuals belonging to *Q. cerris* (Figure 8).

It is seen that individuals whose leaf edges are toothed, came together at the bottom of the graph (Figure 8). Because of the leaves of *Q. libani* do not show much variation in the leaf length and in the formation of teeth, individuals grouped in close proximity to each other. Their leaf widths are wider as compared to *Q. trojana*'s. Nevertheless, the leaves of some individuals belonging to *Q. libani* showed very little overlap with the leaves of *Q. brantii* and *Q. cerris* (Figure 8).

The leaves of *Q. trojana* have a regular tooth structure. However, in general the top parts of leaf show bending toward the left or right. While the leaf lengths have a variability according to the degrees of this bending, but leaf widths are quite homogenous. For these reasons, the leaves of *Q. trojana* and Q. *libani* mixed and so, large parts of these groups overlapped each other (Figure 8). As the laves of *Q. trojana* overlapped the leaves of *Q. brantii*, they also overlapped the leaves of *Q. cerris* very little (Figure 8).

Q. ithaburensis showed quite variation in terms of leaf lenght, leaf width, and edge structure. Because the leaves belonging to this taxa showed overlapping in varying size with all of other leaves of taxa (Figure 8). Despite the leaves belonging to this taxa have not toothed edges, they overlapped with the leaves of *Q. libani* and *Q. trojana* in some parts (Figure 8). On the other hand, because of the leaves with irregularly lobed, they overlapped with the leaves of *Q. brantii* and *Q. cerris* in some parts (Figure 8).

With a general evaluation, while the leaves of *Q. branti* and *Q. cerris* formed two distinct groups, the leaves of *Q. ithaburensis* showed the distribution between these two groups and overlapped in some parts of these groups (Figure 8). The groups belonging to these three taxa generally possess irregular shallow or deep lobed leaves. The groups of *Q. libani* and *Q. trojana* whose leaves are both regular or irregular toothed, showed a large proportion overlapped with each other (Figure 8). While they showed very little overlapping with the group of *Q. cerris*, they showed more overlapping with the groups of *Q. brantii* and *Q. ithaburensis* (Figure 8). Thus, it can be said that *Cerris* section showed two large groups in the PCA graph (Figure 8). First of them, which include the leaves of *Q. cerris*, *Q. brantii*, and *Q. ithaburensis* having regular-irregular lobed leaves, was in the upper parts of the graph (Figure 8). Other group ,which include the leaves of *Q. libani* and *Q. trojana* having regular-irregular toothed leaves, was in the lower parts of the graph (Figure 8).

When it has analyzed the morphology of acorns of these species, it is seen that the *Q. cerris*, *Q ithaburensis*, and *Q. brantii* have quite similar acorn structures to each other (Bakış, 2005). However, the species of *Q. libani* and *Q. trojana* have similar acorn morphology to each other (Bakış, 2005). On the other hand, the geographical distributions of the species of *Q. brantii* and *Q. ithaburensis* were separated by the Anatolian Diagonal and have been shown that they created allopatric populations in west and east parts of the diagonal (Uslu et al., 2011). In the same way, both *Q. trojana* and *Q. libani* created allopatric populations isolated from each other by the Anatolian Diagonal (Uslu et al., 2011). Because of these reasons, the cases of hybridization among them is quite low. Therefore, it can be said that the leaves falling into the same groups were not hybrid individuals. On the other hand, because of the quite large distributions of *Q. cerris* individuals, they can form hybrids with *Q*. *brantii* and *Q. ithaburensis* in different leaf forms (Kasaplıgil, 1981**;** Davis, 1971; Yaltirik, 1984). Therefore, it can be said that these groups in which they overlapped with each others in terms of hybrid leaf morphology. On the other hand, while *Q. cerris* show widely distribution in our country, it can be said that they gave quite a low hybridization with *Q. trojana* and *Q. libani* (Yaltirik, 1984).

The leaves of species belonging to *Ilex* section formed two large groups. While the species of *Q. aucheri* and *Q. coccifera* overlapped significantly with each other, *Q. ilex* species formed distinct group (Figure 9). On the other hand, the leaves of *Q. aucheri* and *Q. coccifera* showed quite a large variation in terms of length and width. However, the leaves of *Q. ilex* formed a rather homogenous group showing less variation. Because, the distribution of *Q. ilex* is more limited and is less affected by environmental conditions (Uslu et al., 2011). *Q. coccifera* have both regular and irregular mucronate spiny-serrated leaves. However, because of these mucronate spines were scanned with low sensitivitiy, they took place among the non mucronate spine leaves of *Q. aucheri*. As the leaves of these two species are circular and elliptical, they are extremely similar to each other. Leaf teeth of *Q. coccifera* often disappear as gets older and leaves of *Q. coccifera* show similarity to leaves of *Q. aucheri*. These two species are separated from each other in the following way; the lower surface of the leaves of *Q. aucheri* is whitish and hairy and the acorns of *Q. coccifera* are mucronate (Yaltirik, 1984). The leaves of *Q. ilex* are quite different from the leaves of other species. The leaves of this species show variable elliptical form from narrow to wider and their leaf tips show variation ranging from acute to acuminate. Due to these differences, the leaves of *Q. ilex* formed a very homogenous group at the bottom of the graph (Figure 9). Nevertheless, some leaves of the *Q. ilex* have fallen into groups of *Q. aucheri* and *Q. coccifera*. Although *Q. aucheri* and *Q. coccifera* species showed geographically very little sympatric distributions, significantly hybrid status is not seen among them in the nature. The individuals of *Q. ilex* generally show sympatric distribution in some regions with the individuals of *Q. coccifera*. Therefore, it is seen natural hybrids among them (Kasaplıgil, 1981; Yaltirik, 1984).

The leaves of species belonging to *Quercus* section formed a complex grouping. *Q. pontica* formed a group on the left side of the graph due to both their bigger leaf length-width than others and regular toothed leaf edges (Figure 10). But, they showed overlap in some parts with the leaves of *Q. infectoria* whose leaf width-length variations are wide and they have regular shallow lobed and smooth leaf edges. On the other hand, due to the leaves of *Q. macranthera* have too much variation, they almost overlapped with the other species (Figure 10). Similarly, the leaves of *Q. infectoria* also overlapped with the other species (Figure 10). The leaves of *Q. petraea* which is another species having wide leaf variation almost overlapped with the leaves of other species (Figure 10). The leaves of *Q. petraea*, *Q. robur*, *Q. pubescens*, and *Q. virgiliana* overlapped both with each other and with the leaves of *Q. frainetto*, *Q. infectoria*, and *Q. vulcanica* (Figure 10). Many species of this section show overall natural hybridization with each other (Kasaplıgil, 1981; Yaltırık, 1984), especially among the individuals of *Q. petraea*, *Q. robur*, *Q. pubescens*, and *Q. virgiliana* (Borazan, 2003). So, they gave a highly complex groups.

5. CONCLUSION

In this study, oak species in Turkey did not show a complete separation in terms of their leaf shapes both infrasectional and intersectional levels. Complex grouping showed that gene flow continues between species because of hybridization, particularly observed in *Quercus* section. Nevertheless, remarkable results were observed:

1 – It was seen that sections were relatively separated from each other when they analyzed in twain.

2 – Also, species were relatively separated from others in both *Ilex* and *Cerris* sections.

These can be applied to achieve a better result;

1 – Used software package (SHAPE) should be developed in considering of hybrid leaves of *Quercus* spp.

2 – EFA method can be supported with additional other methods of Geometric Morphometrics such as “land marks” and “semilandmarks”.

3 – Pattern analyses must be put forth to enable structurally separation of leaves.

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APPENDIX – GENERAL INFORMATION ON TAXA

Table 4 – General features of genus *Quercus* in TURKEY

Taxa	Structure	Elevation	Endemism
Q. aucheri	Tree or shrub	0 – 450	-
Q. brantii	Small tree or shrub	350 – 1700	-
Q. cerris	Tree	0 – 1900	-
Q. coccifera	Small tree or shrub	0 – 1500	-
Q. frainetto	Tree	20 – 1000	-
Q. hartwissiana	Tree	20 – 1750	-
Q. ilex	Tree or tall shrub	0 – 450	-
Q. infectoria	Small tree or shrub	150 – 1850	-
Q. ithaburensis	Tree	50 – 1700	-
Q. libani	Small tree or shrub	700 – 2000	-
Q. macranthera	Small tree	1000 – 1900	+
Q. petraea	Tree	0 – 2200	+
Q. pontica	Tall shrub	800 – 2100	-
Q. pubescens	Small tree	0 – 1700	-
Q. robur	Tree	100 – 1800	-
Q. trojana	Tree	300 – 1800	-
Q. virgiliana	Tree	100 – 1150	-
Q. vulcanica	Tree	1300 – 1800	+

Table 5 – Date of collection with specimen locations

Species name	Population code	Station number	Collection date	Grid	City	Locality
Q. aucheri	AUC19	19	16.9.2001	C1	Aydın	Söke Pirene
Q. aucheri	AUC114	114	27.10.2002	C1	Aydın	Pirene, Söke, Aydın
Q. aucheri	AUC117	117	28.10.2002	C1	Aydın	Aydın Çine ilçesi, Kuruköy mezarlığı ve karşısı
Q. coccifera	COC20	20	16.9.2001	C1	Aydın	Didim tavşan burnu milli parkı
Q. coccifera	COC77	77	25.9.2002	C6	Gaziantep	Antep-Adıyaman a yol ayrımından 23 km sonra
Q. coccifera	COC78	78	25.9.2002	C6	Gaziantep	Antepten Adıyamana 48. km de
Q. coccifera	COC109	109	26.10.2002	B1	Manisa	Manisa Sipil dağı Milli parkı
Q. coccifera	COC113	113	27.10.2002	B1	İzmir	Kuşadası Milli parkı, Davutlar, dilek yarımadası.
Q. coccifera	COC117	117	28.10.2002	C1	Aydın	Aydın Çine ilçesi, Kuruköy mezarlığı ve karşısı
Q. coccifera	COC168	168	22.10.2003	C4	İçel	Mut-Kırobası, Kırobasına 35 km kala, çukurbağ köyü mezarlığı
Q. coccifera	COC169	169	22.10.2003	C4-C5	İçel	Mut- Kırobası- Silifke arası, silifkeye 28 km kala, yeniçıktı köyü
Q. coccifera	COC174	174	24.10.2003	C6	Antakya	Kırıkhan-Hassa arası, G.Antep'e 133km kala
Q. coccifera	COC176	176	24.10.2003	C6	Kahramanmaraş	Narlı-Pazarcık arası , Pazarcığa 10 km kala
Q. coccifera	COC193	193	9.11.2003	B1-B2	Balıkesir	Ilıca-Balya yol ayrımından , Gönene doğru 2-3 km (G2 e 42km kala)
Q. coccifera	COC219	219	31.10.2004	B1	Çanakkale	Üvecik-Yeniköy arası, 6. km, yol ayrımından sonra
Q. coccifera	COC223	223	25.8.2007	A2	İstanbul	Anadolu Hisarı-Kavacık arası, Elmalı Barajı yolu, İski Gen. Müd. Atık İnş. Karşısı
Q. ilex	ILX41	41	5.10.2001	A3	Zonguldak	Zonguldak Yolu Alaplı b1ölge trafik amirliği
Q. ilex	ILX42	42	5.10.2001	A3	Zonguldak	Alaplıya giderken Kıran sapağı köp den sağa
Q. ilex	ILX90	90	6.10.2002	A3	Düzce	Düzce ayrımından sonra Alaplı yolu (12 km kala)
Q. ilex	ILX91	91	6.10.2002	A3	Zonguldak	Alaplı- Sabırlı Köyü
Q. ilex	ILX201	201	15.9.2003	A3	Zonguldak	Zonguldak Yolu Alaplı bölge trafik amirliği
Q. ilex	ILX206	206	24.10.2004	A3	Düzce	Yığılca, Alaplı arası, Alaplı'ya 4-5 km kala
Q. brantii	BRN15	15	26.8.2006	B7	Elazığ	Sivrice-Maden arası Karanlık dere mevkii
Q. brantii	BRN17	17	27.8.2006	B7	Elazığ	Elazığ-Malatya yolu
Q. brantii	BRN19	19	27.8.2006	C6	Malatya	Malatya-Pütürge arası 15.km
Q. brantii	BRN78	78	25.9.2002	C6	Gaziantep	Antepten Adıyamana 48. km de
Q. brantii	BRN79	79	25.9.2002	C7	Adıyaman	Kahta, Nemrut Milli parkı arkası
Q. brantii	BRN81	81	27.9.2002	B8-C8	Siirt	Baykan-Bitlis arası, Bitlise 35-40 km kala Şehitlik Köyü
Q. brantii	BRN156	156	4.10.2003	B7	Tunceli	Nazimiye Tunceli arası Nazimiyeden sonra 2-3 km.
Q. brantii	BRN158	158	5.10.2003	B7	Elazığ	Arapgir Kemaliye arası, Arapgir den sonra 5-6 km
Q. brantii	BRN172	172	23.10.2003	C6	Antakya	Belen-Antakya arası, Belenden sonra 10-12km
Q. brantii	BRN174	174	24.10.2003	C6	Antakya	Kırıkhan-Hassa arası, G.Antep'e 133km kala
Q. brantii	BRN178	178	25.10.2003	C6	Malatya	Doğanşehir, Malatya arası Doğanşehirden 6-7 km sonra
Q. brantii	BRN283	283	15.04.2013	C6	Kahramanmaraş	Narlı ve Pazarcık arası, Pazarcıktan 10 km sonra
Q. brantii	BRN284	284	15.04.2013	C6	Kahramanmaraş	Narlı ve Pazarcık arası, Pazarcıktan 10 km sonra
Q. cerris	CRR16	16	27.8.2006	B7	Elazığ	Elazığ-Malatya yolu 31.km Gözeli Yolu
Q. cerris	CRR22	22	28.8.2006	B6	Malatya	Kozluca-Akçadağ arası Gürün'den 94km sonra
Q. cerris	CRR25	25	18.9.2001	C2	Muğla	Yerkesik_Derin kuyu köyü yamaçları
Q. cerris	CRR73	73	22.9.2002	A6	Tokat	Çamlıbel-Tokat arası .
Q. cerris	CRR74	74	22.9.2002	A6	Amasya	Turhal, Amasya ya 50 km kala
Q. cerris	CRR76	76	24.9.2002	B6-C6	Kahramanmaraş	Kahramanmaraş, Göksun, radyo vericisinin altı
Q. cerris	CRR97	97	11.10.2002	A3	Bilecik	Bilecik, Kepen Köyü mezarlığı
Q. cerris	CRR98	98	12.10.2002	B2-B3	Kütahya	Akpınardan sonra, Sabuncupınar , 1-2 km kala
Q. cerris	CRR100	100	12.10.2002	B2	Kütahya	Kütahya- Tavşanlı arası
Q. cerris	CRR101	101	13.10.2002	B3	Kütahya	Kütahya- Afyon yolu 10. km
Q. cerris	CRR102	102	13.10.2002	B3	Kütahya	Kütahya, Zafertepeye 5 km kala
Q. cerris	CRR121	121	8.11.2002	A2	Bursa	M. Kemal-paşa, Deveci konağı, Kösehoroz'a yakın
Q. cerris	CRR129	129	11.11.2002	B1	Çanakkale	Assos - Ayvacık arası, Söğütlü köyü çıkışı
Q. cerris	CRR136	136	28.9.2003	A5	Çorum	Çorum- Sungurlu- Alaca ayrımı, Çorum dan 33 km sonra
Q. cerris	CRR138	138	28.9.2003	A5-B5	Yozgat	Aydıncık-Çekerek arası Bazlambaç köyünden 5 km sonra
Q. cerris	CRR161	161	6.10.2003	B6-B7	Malatya	Malatya-Darende arası Darendeye 53 km kala
Q. cerris	CRR178	178	25.10.2003	C6	Malatya	Doğanşehir, Malatya arası Doğanşehirden 6-7 km sonra
Q. cerris	CRR179	179	25.10.2003	C6	Kahramanmaraş	Elbistan-Göksun arası 35. km Yazı köyü civarı
Q. cerris	CRR180	180	25.10.2003	B6-C6	Kahramanmaraş	Elbistan-Göksun arası , Göksuna 17 km kala
Q. cerris	CRR192	192	9.11.2003	B1	Balıkesir	Ilıca-Balya Gönen yol ayrımı, Ilıca dan 5 km sonra
Q. cerris	CRR193	193	9.11.2003	B1-B2	Balıkesir	Ilıca-Balya yol ayrırımından , Gönene doğru 2-3 km (G2 e 42km kala)
Q. cerris	CRR195	195	9.11.2003	A1	Çanakkale	Biga-Çan arası Çan2a 18-20 km kala
Q. cerris	CRR196	196	9.11.2003	A1-A2	Çanakkale	Çan-Yenice arası Yeniceye 5-6 km kala
Q. cerris	CRR200	200	10.11.2003	B1	İzmir	Bergama-Kozak arası, Ayvalık'a 42 km kala
Q. cerris	CRR203	203	23.10.2004	A4	Ankara	Sorgun-Güdül arası , Sorgun'dan 10-15 km sonra
Q. cerris	CRR251	251	4.7.2009	A3	Sakarya	Karasu Kayacık köyü yakınları
Q. cerris	CRR260	260	17.9.2009	C2	Muğla	Yerkesik ile Ula arası, Yerkesikten 1-2km sonra, Hacı Efendi Eren mevkii
Q. cerris	CRR266	266	22.9.2009	A1	Çanakkale	Küçük kuyu-Ayvacık arası, Akçay'dan 40-41km sonra, Arık köyü sapağında 1.km de
Q. cerris	CRR269	269	13.10.2009	A3	Bolu	Mudurnu-Sakarya arası, Mudurnu'dan 6-7km sonra
Q. cerris	CRR271	271	24.10.2009	A3	Düzce	Gümüşova-Hendek arası, Düzce'den 20km sonra, Halilbey köyü, Gümüşovadan sonra
Q. trojana	TRJ17	17	15.9.2001	B3	Afyon	Bayat a 5 Km kala
Q. trojana	TRJ27	27	19.9.2001	C2	Muğla	Kaş-Finike arası Yazırbeli y.
Q. trojana	TRJ31	31	20.9.2001	C3	Isparta	Eğridir Y.Gökdere. Kasnak Meşesi Orm.
Q. trojana	TRJ33	33	21.9.2001	C3	Konya	Yenişarbademli-Beyşehir arası
Q. trojana	TRJ98	98	12.10.2002	B2-B3	Kütahya	Akpınardan sonra, Sabuncupınar , 1-2 km kala
Q. trojana	TRJ105	105	13.10.2002	B2	Uşak	Uşaktan Sivaslıya 17 km kala
Q. trojana	TRJ107	107	14.10.2002	B2	Kütahya	Simav-Emet arası, Emet'e 7 km kala
Q. trojana	TRJ120	120	8.11.2002	A2	Bursa	Bursa-Karacabey arası
Q. trojana	TRJ121	121	8.11.2002	A2	Bursa	M. Kemal-paşa, Deveci konağı, Kösehoroz'a yakın
Q. trojana	TRJ163	163	21.10.2003	C4	Karaman	Karaman- Yeşildere ayrımından yeşildereye doğru
Q. trojana	TRJ164	164	21.10.2003	C4	Karaman	Yeşildere- Karaman arası, Üçbaş köyünden 2km sonra
Q. trojana	TRJ168	168	22.10.2003	C4	İçel	Mut-Kırobası, Kırobasına 35 km kala, çukurbağ köyü mezarlığı
Q. trojana	TRJ185	185	8.11.2003	B2-B3	Kütahya	Kütahya- Çavdarhisar yol ayrımından, 6-7 km Çavdarh. dogru
Q. trojana	TRJ186	186	8.11.2003	B2	Kütahya	Çavdarhisar- Gediz arası, Çavdarh. Dan 10 km. Sonra
Q. trojana	TRJ193	193	9.11.2003	B1-B2	Balıkesir	Ilıca-Balya yol ayrırımından , Gönene doğru 2-3 km (G2 e 42km kala)
Q. trojana	TRJ220	220	31.10.2004	B1	Çanakkale	Yukarı Kızılkeçili, Kurtepesi mevkii, Çanakkale-Lapseki arası, Çanakkale'ye 17 km kala
Q. trojana	TRJ265	265	21.8.2009	B2	Uşak	Sivaslı-Uşak arası, Sivaslıdan 12km sonra, Kovaboyalık köyü yolu
Q. trojana	TRJ267	267	21.8.2009	B1	Çanakkale	Yukarı Kızılkeçili, Kurtepesi mevkii, Çanakkale-Lapseki arası, Çanakkale'ye 17 km kala
Q. libani	LIB14	14	8.9.2001	B7	Erzincan	Tercan_Erzincan arası
Q. libani	LIB18	18	27.8.2006	B6	Malatya	Malatya-Pütürge arası 25.km
Q. libani	LIB24	24	29.8.2006	C7	Adıyaman	Gölbaşı-Pazarcık arası Poyarağa***** 24km kala Pazarcık sınırı
Q. libani	LIB35	35	22.9.2001	C4	Konya	Hadim 'e 4 km kala
Q. libani	LIB36	36	22.9.2001	C4	Karaman	Ermenek Başyayla arası Adiller köyü
Q. libani	LIB82	82	27.9.2002	B9	Bitlis	Bitlis- Hizan yol ayrımından sonra 6. km
Q. libani	LIB87	87	28.9.2002	B8	Bingöl	Muş- Solhan arası, Arakonak köyü mevkii
Q. libani	LIB146	146	2.10.2003	B9	Van	Van-Çatak- Dalbastı köyünden 24km sonra
Q. libani	LIB151	151	4.10.2003	B7	Erzincan	Tercan Üzümlü arası Tercan dan 46 km sonra
Q. libani	LIB152	152	4.10.2003	B8	Tunceli	Tercan Pülümür ayrımından 6 km sonra
Q. libani	LIB154	154	4.10.2003	B7	Tunceli	Tercan Pülümür ayrımından sonra 31. km.
Q. libani	LIB155	155	4.10.2003	B7	Tunceli	Pülümür Nazimiye arası, Nazimiye ye 16 km kala
Q. libani	LIB159	159	5.10.2003	B7	Elazığ	Kemaliye ye 30 km kala
Q. libani	LIB283	283	15.04.2013	C6	Kahramanmaraş	Narlı ve Pazarcık arası, Pazarcıktan 10 km sonra
Q. ithaburensis	ITH38	38	22.9.2001	C4	Karaman	Ermenek Mut arası
Q. ithaburensis	ITH67	67	16.11.2001	B1	Balıkesir	Ören
Q. ithaburensis	ITH103	103	13.10.2002	B2	Uşak	Banaz Uşak arası, Kızılcaören Kö.
Q. ithaburensis	ITH104	104	13.10.2002	B2	Uşak	Banaz, Uşak arası, önceki istasyondan 8 km sonra
Q. ithaburensis	ITH105	105	13.10.2002	B2	Uşak	Uşaktan Sivaslıya 17 km kala
Q. ithaburensis	ITH111	111	26.10.2002	B1	İzmir	Soma-Bergama arası, Hamidiye-Karaçan Köyü ayırımı
Q. ithaburensis	ITH119	119	29.10.2002	B2	Manisa	Salihliden sonra, Kulaya 20-25 km kala
Q. ithaburensis	ITH122	122	9.11.2002	B1	Balıkesir	Ören Parkı, korunmuş İthaburensis
Q. ithaburensis	ITH123	123	9.11.2002	B1	Balıkesir	Pelitköyün 5 km güneyi, Horozlu mevkii
Q. ithaburensis	ITH124	124	9.11.2002	B1	İzmir	Dikili-Çandarlı arası, Dikili den sonra 10 km
Q. ithaburensis	ITH126	126	9.11.2002	B1	İzmir	Bergama- İvrindi ayrımı, İvrindiye 67km kala
Q. ithaburensis	ITH130	130	12.11.2002	B1	Çanakkale	Bozcaada iskelesi yakını, Geyikli, Ezine
Q. ithaburensis	ITH198	198	10.11.2003	B1	Balıkesir	Ayvalık-Dikili arası, salihler köyü
Q. ithaburensis	ITH217	217	31.10.2004	B1	Çanakkale	Çanakkale-İzmir arası, Boacaada ayrımından 3-4 km sonra
Q. ithaburensis	ITH218	218	31.10.2004	B1	Çanakkale	Çanakkale-Üvecik, Yeniköy ayrımı 3-4. km si
Q. ithaburensis	ITH253	253	16.9.2009	B1	İzmir	Bademli köyü-Denizköy köyü arası, Dikiliden sonra 17-18km sonra
Q. ithaburensis	ITH259	259	17.9.2009	C2	Muğla	Yerkesik, Ula'dan 24-25 km sonra

Table 5 - Continued from previous page

Q. ithaburensis	ITH265	265	24.10.2009	B2	Uşak	Sivaslı-Uşak arası, Sivaslıdan 12km sonra, Kovaboyalık köyü yolu
Q. infectoria	INF12	12	26.8.2006	B7	Erzincan	Kemaliye-İliç arası Kocaçimen, Çaldere- Kabataş ayrımı
Q. infectoria	INF16	16	27.8.2006	B7	Elazığ	Elazığ-Malatya yolu 31.km Gözeli Yolu
Q. infectoria	INF20	20	28.8.2006	B7	Malatya	Malatya-Hekimhan arası 26.km
Q. infectoria	INF136	136	28.9.2003	A5	Çorum	Çorum- Sungurlu- Alaca ayrımı, Çorum dan 33 km sonra
Q. infectoria	INF137	137	28.9.2003	A5	Çorum	Alaca, Aydıncık arası, Sancı köyünün üstleri
Q. infectoria	INF145	145	2.10.2003	B9	Van	Van-Çatak- Dalbastı köyünden 20 km sonra
Q. infectoria	INF152	152	4.10.2003	B8	Tunceli	Tercan Pülümür ayrımından 6 km sonra
Q. infectoria	INF160	160	5.10.2003	B7	Elazığ	Kemaliye-Arapgir arası, Arapgire 20 km kala
Q. infectoria	INF165	165	22.10.2003	C4	Karaman	Karaman-Bucak Kışla- Morçalı yol ayrımı
Q. infectoria	INF168	168	22.10.2003	C4	İçel	Mut-Kırobası, Kırobasına 35 km kala, çukurbağ köyü mezarlığı
Q. infectoria	INF190	190	9.11.2003	B2	Balıkesir	Balıkesir-Ilıca yol ayrımı ile ılıca rasından sonra 5-6 km
Q. infectoria	INF194	194	9.11.2003	B1	Balıkesir	Gönen-Sarıköy arası Gönenden 5. km sonra
Q. macranthera	MAC2	2	23.8.2006	A5	Yozgat	Saraykent_Akdağmadeni arası, akdağmadeni civarları
Q. macranthera	MAC3	3	24.8.2006	A6	Sivas	Zara-Suşehri arası 16. km
Q. macranthera	MAC6	6	24.8.2006	A7	Giresun	Alucra - Hacıhasan yolu üzeri
Q. macranthera	MAC11	11	7.9.2001	A9	Erzurum	Kars –Erzurum Aydogdu Köyü Sarılot mevkii
Q. macranthera	MAC12	12	8.9.2001	A9	Erzurum	Göle-Aydoğdu Köyü Güneyi Acısu
Q. macranthera	MAC45	45	12.10.2001	A4	Kastamonu	Kastamonu to İnebolu Seydiler civarı Taş ocağı yakını
Q. macranthera	MAC139	139	29.9.2003	B6	Sivas	Erzincan- Sivas arası, Sivastan 145 km sonra
Q. macranthera	MAC140	140	29.9.2003	B6	Sivas	Sivas-Erzincan arası, İmranlıdan sonra
Q. macranthera	MAC142	142	29.9.2003	A7	Giresun	Çamoluk-Alucra arası, sivastan sonra 246. km
Q. macranthera	MAC143	143	29.9.2003	A7	Gümüşhane	Köse, gümüşhane arası, Gümş. Ye 30 km kala
Q. macranthera	MAC144	144	30.9.2003	A7	Gümüşhane	Gümüşhane- Bayburt arası. Güm. Den sonra 36.km
Q. macranthera	MAC148	148	3.10.2003	B9	Bitlis	Gevaş-Tatvan arası
Q. macranthera	MAC150	150	4.10.2003	B8	Erzurum	Erzurum Erzincan yol ayrımı, Erzurumdan sonra
Q. macranthera	MAC152	152	4.10.2003	B8	Tunceli	Tercan Pülümür ayrımından 6 km sonra
Q. macranthera	MAC153	153	4.10.2003	B7-B8	Tunceli	Tercan Pülümür ayrımından sonra 27 . km
Q. pubescens	PUB4	4	24.8.2006	A6	Sivas	Zara-Suşehri arası Zaradan 18. km
Q. pubescens	PUB75	75	22.9.2002	A5	Çorum	Osmancık a giderken sağda Gümüşhacıköy
Q. pubescens	PUB99	99	12.10.2002	B2-B3	Kütahya	Kütahya Türkmen dağı, Kale yakınları
Q. pubescens	PUB102	102	13.10.2002	B3	Kütahya	Kütahya, Zafertepeye 5 km kala
Q. pubescens	PUB132	132	27.9.2003	A5	Çorum	İskilip-Dodurga arası , Velek Köyünün üstü
Q. pubescens	PUB133	133	27.9.2003	A5	Çorum	İskilip Dodurga arası Velekten Dodurgaya 10-15km sonra
Q. pubescens	PUB134	134	27.9.2003	A5	Çorum	Dodurga-İskilip arası, Asarcık Köyünden sonra 25 km.
Q. pubescens	PUB135	135	27.9.2003	A5	Çorum	Laçin-Çorum arası, Laçinden 2-3 km sonra
Q. pubescens	PUB141	141	29.9.2003	B6	Sivas	Gölova- Çamoluk, seme çayı boyu, gölovaya 25 km kala
Q. pubescens	PUB182	182	7.11.2003	A3	Bolu	Mudurnu, Göynük, Adapazarı yolu, Mudurnuda 10 km sonra
Q. petraea	PET9	9	4.9.2001	A6	Sivas	Mesudiye-Koyulhisar arası
Q. petraea	PET39	39	5.10.2001	A3	Düzce	A.İ.B.Üniversitesi Orman Fak. Kampus karşısı
Q. petraea	PET42	42	5.10.2001	A3	Zonguldak	Alaplıya giderken Kıran sapağı köp den sağa
Q. petraea	PET43	43	12.10.2001	A4	Kastamonu	Araç a 25 km kala Kastamonu ya giderken
Q. petraea	PET44	44	12.10.2001	A4	Kastamonu	Kastamonu-Araç Samatlar ormanı
Q. petraea	PET48	48	12.10.2001	A5	Sinop	Sinop a 40 km kala Yol kenarı
Q. petraea	PET49	49	13.10.2001	A4	Kastamonu	Kastamonu-Daday arası, Kastamonu dan sonra 26 km
Q. petraea	PET74	74	22.9.2002	A6	Amasya	Turhal, Amasya ya 50 km kala
Q. petraea	PET149	149	3.10.2003	B9	Bitlis	Tatvan- Muş arası Yukarı kolbaşı köyü
Q. petraea	PET193	193	9.11.2003	B1-B2	Balıkesir	Ilıca-Balya yol ayrırımından , Gönene doğru 2-3 km (G2 e 42km kala)
Q. petraea	PET221	221	6.7.2006	A3	Bolu	Göynük-Çayköy'ün Güney-doğusu
Q. vulcanica	VUL31	31	20.9.2001	C3	Isparta	Eğridir Y.Gökdere. Kasnak Meşesi Orm.
Q. vulcanica	VUL162	162	21.10.2003	C4	Karaman	Karaman-Kılbasan- Karapınar arası Kara dağ.
Q. virgiliana	VIR43	43	12.10.2001	A4	Kastamonu	Araç a 25 km kala Kastamonu ya giderken
Q. robur	ROB9	9	25.8.2006	B7	Erzincan	Tercan-Erzincan arası DDY üzeri Üzümlüğe 46km kala
Q. robur	ROB80	80	26.9.2002	C7-C8	Diyarbakır	Universite sosyal tesislerin bahçesi
Q. robur	ROB83	83	28.9.2002	B8-B9	Muş, Bitlis	Tatvan- Muş arası, Yukarıkolbaşı köyü yolu
Q. robur	ROB84	84	28.9.2002	B8-B9	Bitlis	Tatvan- Muş arası, Güroymak' a 4km kala
Q. robur	ROB85	85	28.9.2002	B8 B9	Bitlis	Günkırılı beldesi, Güroymağa 6-7 km kala
Q. robur	ROB140	140	29.9.2003	B6	Sivas	Sivas-Erzincan arası, İmranlıdan sonra
Q. robur	ROB189	189	8.11.2003	B2	Balıkesir	Sındırgı-Gölcük arası Gölcük'e 15 km kala
Q. pontica	PON10	10	6.9.2001	A8	Rize	Rize Güneysu-BüyükHan yaylası
Q. pontica	PON62	62	10.10.2001	A9	Artvin	Artvin-Borçka Karşıgöl şefliği karagöl mevkii
Q. pontica	PON63	63	10.10.2001	A9	Artvin	Artvin arhavii mevkii
Q. pontica	PON66	66	29.10.2001	A8	Rize	Rize Güneysu büyükhan yaylası
Q. hartwissiana	HRT46	46	12.10.2001	A5	Sinop	Sinop a 85 km kala Büyükdüz köyünün girişi
Q. hartwissiana	HRT86	86	28.9.2002	B8	Bingöl	Muş-Solhan arası Gedik mevkii. Solhan' a 13 km kala
Q. frainetto	FRA40	40	5.10.2001	A3	Düzce	Orm Fak prefabrik güney-doğu
Q. frainetto	FRA89	89	6.10.2002	A3	Düzce	Düzce Tıp fak karşısı
Q. frainetto	FRA92	92	5.10.2002	A3	Sakarya	Beylice- hendek Çerkezler semti..
Q. frainetto	FRA95	95	11.10.2002	A3	Bilecik	Bilecik, Ulupınar mevkii
Q. frainetto	FRA187	187	8.11.2003	B2	Kütahya	Simav-Demirci-Sındırgı yol ayrımından sonra 3-4 km sındırgıya doğru
Q. frainetto	FRA188	188	8.11.2003	B2	Balıkesir	Simav-Sındırgı arası Sındırgıya 42 km kala
Q. frainetto	FRA191	191	9.11.2003	B2	Balıkesir	Balıkesir-Şamlı arası Şamlıdan sonra
Q. frainetto	FRA208	208	28.10.2004	A2	İstanbul	Zekeriyaköy-Bahçeköy arası, Gümüşdere'den 3-4 km sonra
Q. frainetto	FRA214	214	30.10.2004	A1	Edirne	Uzunköprü-Meriç arası, Meriç'e 1-2 km kala

Table 6 – Hybridization of some species in Turkey

1. *Q. brantii x Q. infectoria*
2. *Q. brantii x Q. vulcanica*
3. *Q. brantii x Q libani*
4. *Q. cerris x Q. infectoria*
5. *Q. cerris x Q. libani*
6. *Q. cerris x Q. pubescens*
7. *Q. frainetto x Q. pubescens*
8. *Q. frainetto x Q. vulcanica*
9. *Q. hartwissiana x Q. petraea*
10. *Q. infectoria x Q. robur*
11. *Q. infectoria x Q. pubescens*
12. *Q. infectoria x Q. libani*
13. *Q. macranthera x Q. pubescens*
14. *Q. petraea x Q. cerris*
15. *Q. petraea x Q. pubescens*
16. *Q. petraea x Q. robur*