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Morphological diversity and a germplasm survey of three wild *Pistacia* species in Turkey

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Abstract

The common wild *Pistacia* species in Turkey are *P. terebinthus* L., *P. atlantica* Desf. and *P. eurycarpa* Yalt. A total of 65 *Pistacia* genotypes from different parts of Turkey were surveyed and characterized phenotypically and morphologically for this study: 10 *P. eurycarpa* genotypes from Siirt and Gaziantep provinces, 45 *P. atlantica* and 10 *P. terebinthus* genotypes from Adana, Aydin and Manisa provinces. Their seeds were sampled and seedlings were produced to characterize as compared to the their leaves with leaf traits of maternal trees. A total of 30 characters (four tree, 19 leaf and seven nut) were used to characterize this collection, including ten quantitative characters and 20 qualitative characters. Both at the inter- and intra-specific level, the 65 genotypes displayed high diversity. Several characters were found to be diagnostic at the species level among the three species. Correlations between characters were found for each species separately. Nut weight was positively correlated with terminal leaflet length and with nut dimensions in all three species. Morphological description of several *Pistacia* genotypes revealed inter-specific hybrids.

Introduction

The genus *Pistacia* is a member of the Anacardiaceae family, and consists of 11 species (Zohary 1952). *P. vera* L. has edible nuts of great commercial importance, while the most common wild *Pistacia* species in Turkey are *P. terebinthus* L., *P. eurycarpa* Yalt. and *P. atlantica* Desf. The nuts of the other species are also used for local consumption, oil and soap production (Kafkas 1995), however, their main economic importance derives from using their seeds as rootstock materials for *P. vera*. Turkey has huge *Pistacia* germplasm resources, including approximately 66 millions wild *Pistacia* trees (Kuru and Ozsabuncuoglu 1990), found as forests or individual trees. Their phenotypic appearance and productivity are highly variable. In the last several decades, wild *Pistacia* trees are used as rootstock for *P. vera* by top-working, i.e., grafting wild *Pistacia* trees with edible *P. vera* as a source of additional income for the farmers (Bilgen 1968; Kaska and Bilgen 1988). Wild *P. atlantica* trees grow in Marmara, Aegean, Mediterranean, Black Sea and Middle Anatolia regions. *P. terebinthus* is the most common wild *Pistacia* species and it grows naturally in all the regions of Turkey except for the too cold and rainy areas (Bilgen 1968).

The first monographic study of the genus was made by Engler (1883) who described eight species and a few varieties. After Engler, several additional species have been described by various authors, and so far the most complete taxonomic study was done by Zohary (1952, 1972). In his monography, the genus is subdivided into four sections. The main diagnostic traits used to distinguish between the various species are mainly leaf characteristics and nut morphology. Yaltirik (1967) classified *Pistacia* species in Turkey and added a new species, called *P. eurycarpa* that grows in Bitlis, Mardin and Hakkari provinces. Al-Yafi (1978) divided *P. atlantica* into subspecies according to their leaf morphology. Kokwaro and Gillett (1980) described a new *Pistacia* species in East Africa, *P. aethiopica* Kokwaro. Lin et al. (1984) compared leaf morphology, photosynthesis and leaf conductance of nine *Pistacia* species. El-Oqlah (1996) described Jordanian *Pistacia* species morphologically, anatomically and palynologically. An interesting attempt was done by Grundwag and Werker (1976) to characterize *Pistacia* species growing in Israel according to their wood anatomy.

Each of the above phenotypical and morphological studies used only a few traits to describe *Pistacia* species. Some of the characters remained poorly defined and it was unclear whether they can be used for classification. We set to characterize the phenotypical and morphological diversity within the important wild *Pistacia* species of Turkey at the inter- and intra-specific level, using a larger amount of qualitative and quantitative traits, and to examine possible associations between traits in each of the species. Morphological traits of less known species, *P. eurycarpa*, are given in detail as well. Additional studies that evaluate the seedling progeny of the 65 genotypes for their quality in rootstock breeding have been undertaken.

Materials and methods

Plant material and sampling

A total of 65 *Pistacia* genotypes from different parts of Turkey were labeled *in situ* and characterized phenotypically and morphologically for this study: 10 *P. eurycarpa* genotypes from Siirt and Gaziantep provinces, 45 *P. atlantica* and 10 *P. terebinthus* genotypes from Adana, Aydin and Manisa provinces (Figure 1). Their seeds were also sampled and germinated to produce seedlings, in order to compare morphological characters between maternal trees and their seedling progeny. For leaf traits, representative leaves were collected from the trees after new shoots were lignified. Sampling was done in the lowest and uppermost parts of branches. For description of nut traits, nuts were harvested (about 1 kg/tree), and dried at ambient temperature during several days.

Description of Pistacia trees

The wild trees were described with respect to tree, leaf and nut morphology based on *Pistacia* descriptors developed by the International Plant Genetic Resources Institute (IPGRI 1998) with minor modifications. A total of 30 characters (four tree-, 19 leaf- and seven nut-traits) were used to characterize the *Pistacia* germplasm. Ten characters out of 30 were quantitative and 20 were qualitative. Table 1,2 enlist the traits surveyed in this study.

Tree or shrub characters of the genotypes were described by direct observations. For leaf and nut qualitative traits, predominant character was indicated. Representative ten leaves were used for mea-

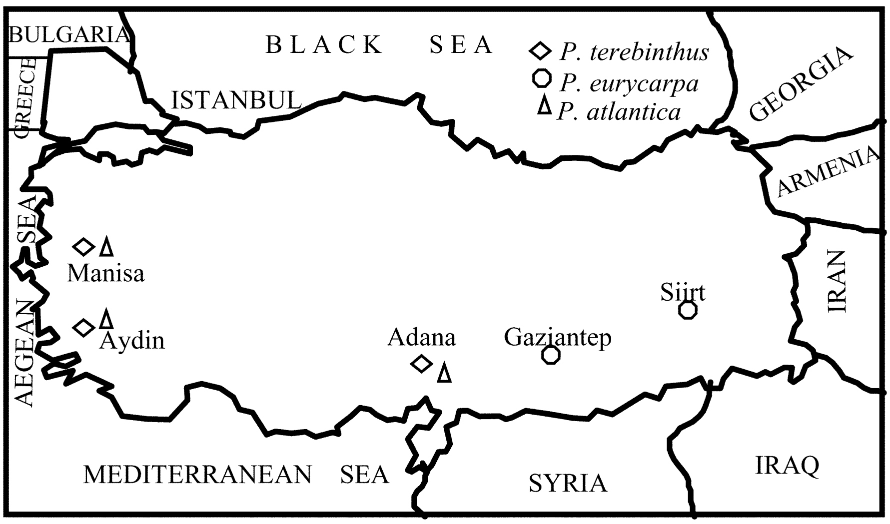

Figure 1. Sampling sites of *Pistacia* trees in this study.

Table 1. The list of qualitative traits and their character states.

NO	TRAITS	CHARACTER STATES		
Tree descriptors				
1.	Tree vigor	low	intermediate	high
2.	Growth habit	shrub	branched	single
3.	Branching habit	sparse	intermediate	dense
4.	Leaf persistency	evergreen	deciduous	
Leaf descriptors				
5.	Leaf color	light green	green	dark green
6.	Leaf indumentum	glabrous	puberulent	
7.	Leaf waxiness	absent	present	
8.	Resin smell	weak	intermediate	strong
9.	Leaf rachis wing	absent	present	
10.	Terminal leaflet	absent	present	
11.	Terminal leaflet size	smaller	similar	bigger
12.	Leaf petiole	absent	present	
13.	Leaflet petiole	absent	present	
14.	Leaf petiole shape	rounded	angled	flattened
15–16.	Leaflet and terminal	lanceolate	elliptical	narrow elliptical
	leaflet shapes	ovate	ovate-oblong	oblong
17.	Terminal leaflet	mucronulate	acute obtuse	retuse
	apex shape	acumunate	mucronate	emarginate
Nut descriptors				
18.	Hull tip	absent	present	
19.	Hull texture	fleshy-juice	fleshy-dry	
20.	Nut shape	obovoid	globular	obovoid-globular
		globular-compressed		

surement of leaf characters. For nut weight, 400 nuts and for nut dimensions 100 nuts were used.

Statistical analysis

For quantitative characters, the data was computed for each trait and species. The data was analyzed by one-way ANOVA model. Tukey's procedure (HSD, $P = 0.05$) was used to test for significant differences between the species. Correlations were performed between quantitative traits at $P = 0.05$, 0.01 and 0.001 levels. All statistical analyses were performed using the SPSS (version 6.0) package program.

Results and discussion

Quantitative characters

Ten quantitative leaf and nut traits were scored in the

Table 2. The list of quantitative traits and their measures.

NO	TRAITS	CHARACTER MEASURES
Leaf descriptors		
1.	Leaf length (cm)	from the base of leaf petiole to the tip of terminal leaflet
2.	Leaf width (cm)	at the widest part of leaf
3.	No. of leaflet pairs	counted using ten representative leaves
4.	T. leaflet length	from the base of leaflet petiole to the tip of the terminal leaflet
5.	T. leaflet width	at the widest part of the terminal leaflet
6.	Leaf petiole length	from the base of leaf petiole to starting point of leaflets
Nut descriptors		
7.	Nut weight:	weighting 400 nuts
8.	Nut length	between the most distant points along main seed axis
9.	Nut width	at the widest part perpendicular to the main seed axis
10.	Nut thickness	at the widest part perpendicular to the suture

65 individual trees (genotypes). These traits are listed in Table 2. Table 3 shows the full data set of these 10 traits in 30 representative *Pistacia* genotypes, and Table 4 compares the three wild species in terms of these quantitative characteristics. The average leaf length, terminal leaflet length and width, leaf petiole length and all the nut characters were significantly different between each of the three species. Leaf width was not significantly different between *P. eurycarpa* and *P. terebinthus*, whereas it was significant between these two species and *P. atlantica*. The number of leaflet pairs did not differ significantly between *P. terebinthus* and *P. atlantica*, whereas it was significantly different between these two species and *P. eurycarpa*.

As for the leaf characters, the leaf length and width results were similar to the literature (Zohary 1952, 1972; Yaltirik 1967). The size of terminal leaflet was not reported in the literature. Since terminal leaflet sizes of the three species are significantly different from each other, measurement of terminal leaflet length and width may be used to distinguish these three species. For leaf petiole length, genotype 45-A-18 had the longest leaf petiole (5.4 cm) within *P. atlantica*, but all the other *P. atlantica* genotypes had no more than 4 cm. *P. atlantica* was found to have shorter leaf petioles than the two other species whereas *P. eurycarpa* had the longest ones.

As for number of leaflet pairs per leaf, the results were similar to literature (Zohary 1952, 1972; Yaltirik 1967). According to Zohary, less number of leaflet pairs indicates more ancestral species, and therefore *P. vera* is the most ancestral species and followed by *P. eurycarpa*, *P. atlantica* and *P. terebinthus* according to our study.

The heaviest nuts were found in *P. eurycarpa*, whereas the lightest ones were in *P. terebinthus*. The heaviest nuts within *P. eurycarpa* genotypes were

Table 3. Characteristics of 30 representative *Pistacia* genotypes out of 65 based on quantitative characters along with standard deviation.

Genotype code	Leaf length	Leaf width	No leaflet pairs	T. leaflet length	T. leaflet width	Petiole length	Nut weight	Nut length	Nut width	Nut thickness
01*-T+-01	16.3 ± 1.2	11.1 ± 1.4	3.6 ± 0.5	2.7 ± 0.9	1.3 ± 0.3	4.6 ± 1.2	5.1 ± 0.2	5.0 ± 0.2	4.4 ± 0.1	3.5 ± 0.1
01-T-02	17.0 ± 1.1	11.2 ± 1.7	4.5 ± 0.5	3.9 ± 0.9	1.6 ± 0.4	5.5 ± 1.3	5.3 ± 0.2	4.2 ± 0.2	5.5 ± 0.1	3.5 ± 0.1
09-T-01	15.6 ± 1.1	10.0 ± 1.3	4.1 ± 0.7	4.9 ± 0.8	1.6 ± 0.3	4.5 ± 1.3	9.2 ± 0.4	5.5 ± 0.1	6.8 ± 0.1	4.4 ± 0.1
09-T-02	14.8 ± 1.8	8.8 ± 1.7	4.0 ± 0.5	2.8 ± 0.7	0.9 ± 0.3	5.0 ± 1.1	6.3 ± 0.2	5.5 ± 0.2	4.9 ± 0.1	3.8 ± 0.1
09-T-03	15.4 ± 1.4	12.5 ± 1.0	3.6 ± 0.7	4.8 ± 1.1	1.3 ± 0.3	4.5 ± 0.6	10.1 ± 0.2	6.4 ± 0.2	5.6 ± 0.1	4.5 ± 0.1
45-T-01	14.7 ± 0.9	10.1 ± 1.2	3.0 ± 0.5	4.9 ± 0.7	1.7 ± 0.3	4.3 ± 1.0	8.9 ± 0.2	6.6 ± 0.1	5.1 ± 0.1	4.3 ± 0.1
45-T-03	14.2 ± 1.1	10.6 ± 1.5	3.0 ± 0.7	4.0 ± 1.2	1.8 ± 0.3	3.8 ± 0.6	5.0 ± 0.2	6.1 ± 0.1	4.3 ± 0.1	3.3 ± 0.1
45-T-05	15.9 ± 1.1	10.3 ± 0.7	3.0 ± 0.7	3.9 ± 0.9	1.4 ± 0.4	4.5 ± 1.4	7.2 ± 0.3	5.3 ± 0.1	5.0 ± 0.2	4.2 ± 0.3
01-A-01	12.8 ± 1.7	9.6 ± 1.6	3.5 ± 0.5	4.5 ± 0.6	2.2 ± 0.4	2.3 ± 0.4	17.2 ± 0.2	6.9 ± 0.7	6.8 ± 0.3	5.4 ± 0.3
01-A-04	13.1 ± 0.8	8.4 ± 0.5	4.7 ± 0.4	3.8 ± 0.5	1.2 ± 0.2	2.2 ± 0.3	11.3 ± 0.3	5.8 ± 0.5	5.9 ± 0.2	4.7 ± 0.1
09-A-01	15.3 ± 1.8	8.7 ± 0.8	4.9 ± 0.3	4.0 ± 0.6	1.9 ± 0.3	2.0 ± 0.7	16.4 ± 0.1	7.1 ± 0.9	6.8 ± 0.1	5.4 ± 0.1
09-A-04	12.4 ± 1.4	9.2 ± 1.1	4.1 ± 0.7	4.6 ± 0.7	1.8 ± 0.2	2.0 ± 0.6	13.5 ± 0.2	6.3 ± 0.5	6.6 ± 0.2	5.2 ± 0.2
09-A-06	11.9 ± 0.8	7.2 ± 1.0	3.1 ± 0.7	4.0 ± 0.8	1.5 ± 0.2	2.8 ± 0.4	12.2 ± 0.5	6.0 ± 0.6	6.4 ± 0.1	4.9 ± 0.2
09-A-10	14.9 ± 1.8	12.6 ± 0.9	3.4 ± 0.7	6.5 ± 0.7	2.1 ± 0.3	3.5 ± 0.8	11.4 ± 0.2	5.8 ± 0.4	6.0 ± 0.2	5.1 ± 0.1
09-A-12	10.8 ± 1.0	8.2 ± 0.8	3.8 ± 0.8	4.7 ± 0.8	1.9 ± 0.4	1.6 ± 0.4	13.2 ± 0.1	6.4 ± 0.3	6.3 ± 0.2	5.1 ± 0.2
09-A-18	14.2 ± 1.4	9.1 ± 1.0	3.5 ± 0.5	4.8 ± 0.9	1.7 ± 0.3	2.9 ± 0.6	18.8 ± 0.5	6.7 ± 0.5	7.1 ± 0.2	5.6 ± 0.2
45-A-01	12.6 ± 0.8	7.3 ± 0.7	3.6 ± 0.5	3.6 ± 0.3	1.5 ± 0.1	3.9 ± 0.5	13.3 ± 0.2	6.6 ± 0.8	6.8 ± 0.1	4.8 ± 0.2
45-A-04	12.1 ± 0.8	9.1 ± 0.4	2.0 ± 0.4	5.0 ± 0.5	1.8 ± 0.2	2.5 ± 0.2	12.0 ± 0.1	6.3 ± 0.7	6.5 ± 0.1	5.0 ± 0.2
45-A-12	14.5 ± 0.8	8.8 ± 0.5	4.0 ± 0.8	4.2 ± 0.4	1.3 ± 0.1	3.2 ± 0.3	13.5 ± 0.3	5.2 ± 0.2	6.0 ± 0.1	4.8 ± 0.1
45-A-16	12.5 ± 0.6	9.2 ± 0.5	2.9 ± 0.4	4.5 ± 0.6	1.5 ± 0.2	3.1 ± 0.4	8.0 ± 0.3	5.5 ± 0.6	5.6 ± 0.1	4.3 ± 0.1
45-A-17	17.6 ± 0.6	10.8 ± 0.8	3.5 ± 0.5	5.6 ± 0.9	1.9 ± 0.3	3.8 ± 0.3	13.8 ± 0.2	7.1 ± 0.6	6.8 ± 0.2	5.5 ± 0.1
45-A-18	13.4 ± 1.6	9.8 ± 0.8	2.3 ± 0.5	5.4 ± 0.5	2.0 ± 0.2	5.4 ± 0.4	16.9 ± 0.3	6.5 ± 0.5	6.7 ± 0.2	5.5 ± 0.1
27-K-01	19.6 ± 1.7	13.8 ± 1.9	1.9 ± 0.6	6.4 ± 1.1	2.7 ± 0.5	6.9 ± 0.9	34.5 ± 0.5	10.8 ± 0.2	8.2 ± 0.1	5.9 ± 0.1
27-K-02	18.8 ± 1.5	12.8 ± 2.4	2.6 ± 0.5	5.9 ± 0.8	3.1 ± 0.5	6.6 ± 0.6	31.5 ± 1.0	11.7 ± 0.2	9.1 ± 0.2	6.1 ± 0.3
56-K-01	14.3 ± 2.2	9.4 ± 1.8	2.6 ± 0.5	4.6 ± 0.6	1.8 ± 0.2	5.0 ± 0.9	31.9 ± 0.3	7.5 ± 0.2	9.9 ± 0.2	6.7 ± 0.1
56-K-03	14.2 ± 1.9	10.1 ± 1.2	2.6 ± 0.5	5.8 ± 0.9	2.2 ± 0.6	5.4 ± 0.8	19.7 ± 0.2	7.8 ± 0.2	7.5 ± 0.1	5.6 ± 0.2
56-K-04	15.6 ± 1.7	9.5 ± 0.7	2.2 ± 0.6	5.4 ± 0.5	2.4 ± 0.3	5.5 ± 0.2	25.3 ± 0.3	7.9 ± 0.2	8.3 ± 0.2	6.2 ± 0.1
56-K-06	15.7 ± 3.0	11.1 ± 2.3	1.9 ± 0.1	6.2 ± 1.4	2.4 ± 0.5	6.7 ± 1.0	30.4 ± 0.5	8.0 ± 0.2	10.0 ± 0.1	6.8 ± 0.2
56-K-07	14.7 ± 2.6	10.5 ± 2.0	2.8 ± 0.1	5.5 ± 1.4	2.4 ± 0.5	6.1 ± 1.1	35.4 ± 0.3	9.2 ± 0.2	9.9 ± 0.1	6.3 ± 0.2
56-K-08	17.1 ± 1.8	11.6 ± 1.1	1.8 ± 0.4	6.3 ± 0.6	3.3 ± 0.4	7.0 ± 1.5	67.5 ± 0.7	12.7 ± 0.2	11.0 ± 0.4	8.7 ± 0.3

* Province codes: (01) Adana, (09) Aydin, (27) Gaziantep, (45) Manisa, (56) Siirt.+ Species codes: (T) *P. terebinthus*, (A) *P. atlantica*, (K) *P. eurycarpa*.

Table 4. Characteristics of quantitative characters of three *Pistacia* species along with standard deviation.

Characters	*P. terebinthus*		*P. atlantica*		*P. eurycaypa*		$D_{\%5}$
	Range	Average	Range	Average	Range	Average	
Leaf length	14.2–17.0	15.4 ± 1.5 b*	10.8–17.6	13.2 ± 1.8 c	14.2–19.6	16.2 ± 2.7 a	1.362
Leaf width	8.8–12.5	10.7 ± 1.6 a	7.0–12.6	9.1 ± 1.4 b	9.4–13.8	11.1 ± 2.2 a	1.106
Terminal leaflet length	2.7–4.9	3.7 ± 1.2 c	3.6–6.6	4.8 ± 1.0 b	4.6–6.4	5.7 ± 1.0 a	0.720
Terminal leaflet width	0.9–1.8	1.4 ± 0.4 c	1.2–2.4	1.8 ± 0.4 b	1.8–3.3	2.5 ± 0.6 a	0.289
Leaf petiole length	3.8–5.5	4.6 ± 1.1 b	1.6–5.4	3.0 ± 0.9 c	4.7–7.0	6.0 ± 1.2 a	0.687
Number of leaflet pairs	2.9–4.5	3.5 ± 0.8 a	2.0–4.9	3.6 ± 0.8 a	1.8–2.8	2.3 ± 0.6 b	0.526
Nut weight	5.0–10.1	7.1 ± 1.7 c	8.0–18.8	13.7 ± 2.4 b	19.7–67.5	34.5 ± 12.1 a	3.664
Nut thickness	3.3–4.5	4.0 ± 0.5 c	4.2–5.7	5.1 ± 0.4 b	5.6–8.7	6.6 ± 0.9 a	0.366
Nut width	4.3–6.8	5.3 ± 0.7 c	5.6–7.5	6.5 ± 0.5 b	7.5–11.0	9.4 ± 1.1 a	0.458
Nut length	4.2–6.6	5.5 ± 0.7 c	5.2–7.9	6.1 ± 0.8 b	7.5–12.7	9.3 ± 1.8 a	0.686

* Tukey's test at $P = 0.05$ level.

obtained from 56-K-08 genotype, which presented intermediate nut weights with *P. vera*. This genotype may be therefore a hybrid between *P. eurycarpa* and *P. vera*. There is no report in the literature on nut weight of *Pistacia* genotypes, and our study shows that there is a large variation between and within the three species with regard to this important trait. Nut size of *P. atlantica* and *P. terebinthus* genotypes was similar to the data reported by previous studies, whereas the measurements were larger than those of the literature for *P. eurycarpa* (Yaltirik 1967).

We also characterized the leaves of seedlings obtained from the 65 *Pistacia* genotypes (data not shown). In *P. terebinthus* genotypes, leaf length, terminal leaflet length and width values were larger than those of the maternal trees, but the number of leaflet pairs in a typical seedling leaf was smaller than that of the maternal tree leaf. In *P. atlantica* genotypes, the values of the quantitative leaf characters, except for the number of leaflet pairs were higher in the maternal trees than in their seedlings. Also in *P. eurycarpa* genotypes, leaf dimensions were longer in the maternal trees than in their seedlings. The morphological difference between maternal trees and their seedlings is probably due to the juvenile stage of the seedlings, which were one-year old at the time of evaluation. These results indicate that morphological characterization of the *Pistacia* germplasm must be done in the wild, or when the seedlings reached maturity, since using juvenile seedlings for morphological characterization may result in the misidentification of the trees.

Correlations between the quantitative traits

The correlation between pair of traits was tested, and is shown for each species separately (Table 5–7). We found that several leaf characters were significantly correlated with nut characters. In addition, nut weight was significantly correlated with nut dimensions in all three species.

Thus, in *P. terebinthus*, nut weight and nut width were significantly correlated with terminal leaflet length. Nut length was significantly correlated with leaf length and with the number of leaflet pairs. Among leaf characters, leaf length was significantly

Table 5. Trait associations among characters in 10 *P. terebinthus* genotypes

	Leaf width	Terminal leaf length	Terminal leaf width	Leaf petiole length	Number of leaflet pairs	Nut weight	Nut thickness	Nut width	Nut length
Leaf length	0.108	0.048	0.114	0.139	0.295*	− 0.119	− 0.099	0.108	− 0.465**
Leaf width		0.393**	0.354*	0.083	− 0.125	0.119	− 0.004	0.061	− 0.011
Terminal leaf length			0.302*	0.113	0.020	0.353*	0.230	0.479***	0.080
Terminal leaf width				0.097	− 0.071	− 0.232	− 0.198	0.080	− 0.239
Leaf petiole length					0.149	− 0.097	− 0.148	− 0.131	− 0.056
Number of leaflet pairs						− 0.061	− 0.156	0.198	− 0.379**
Nut weight							0.880***	0.593***	0.540***
Nut thickness								0.607***	0.364**
Nut width									− 0.164

* Significant at the 0.05 level; **Significant at the 0.01 level; *** Significant at the 0.001 level.

Table 6. Trait associations among characters in 45 *P. atlantica* genotypes.

	Leaf width	Terminal leaf length	Terminal leaf width	Leaf petiole length	Number of leaflet pairs	Nut weight	Nut thickness	Nut width	Nut length
Leaf length	0.539***	0.295**	0.125	0.339***	0.066	0.092	0.246***	0.146*	0.046
Leaf width		0.601***	0.377***	0.258***	− 0.182**	0.111	0.253***	0.135*	0.042
Terminal leaf length			0.601***	0.146*	− 0.268***	0.205**	0.283***	0.257***	− 0.029
Terminal leaf width				− 0.033	− 0.248***	0.327***	0.297***	0.301***	0.121
Leaf petiole length					− 0.252***	− 0.071	0.072	− 0.010	0.035
Number of leaflet pairs						− 0.083	− 0.104	− 0.137	− 0.073
Nut weight							0.722***	0.723***	0.336***
Nut thickness								0.728***	0.284***
Nut width									0.283***

* Significant at the 0.05 level; **Significant at the 0.01 level; *** Significant at the 0.001 level.

correlated with the number of leaflet pairs, while leaf width was significantly correlated with terminal leaflet dimensions.

In *P. atlantica*, nut weight was significantly correlated with terminal leaf length and width. Nut thickness and nut width were significantly correlated with the dimensions of the leaf, and those of the terminal leaflet. In addition, leaf length was significantly correlated with leaf width, terminal leaflet length and leaf petiole length. Leaf width was significantly correlated with terminal leaflet dimensions, leaf petiole length and the number of leaflet pairs. Terminal leaflet length significantly correlated with terminal leaflet width, and the number of leaflet pairs. Terminal leaflet width and leaf petiole length were both correlated with the number of leaflet pairs.

In *P. eurycarpa*, nut weight was significantly correlated with terminal leaflet width, leaf petiole length and with number of leaflet pairs. Nut thickness correlated significantly with the number of leaflet pairs. Nut length correlated with all other leaf and nut characters. Among leaf characters, leaf length was significantly correlated with leaf width, with terminal leaflet dimensions and with leaf petiole length. Leaf width was significantly correlated with terminal leaf dimensions, and with leaf petiole length. Terminal leaflet length significantly correlated with terminal leaflet width and the number of leaflet pairs. Terminal leaflet width was significantly correlated with leaf petiole length and number of leaflet pairs. Finally, leaf petiole length was significantly correlated with number of leaflet pairs.

These correlations suggest that many of the associations between morphological traits vary between these three species. However, nut weight was associated with terminal leaflet length and with nut dimensions in all three species.

Evaluation of qualitative characters

Four tree-, 13 leaf- and three nut qualitative traits were evaluated by recording the predominant character-state for each trait. Table 8 shows a few of the traits of 30 representative *Pistacia* genotypes, and the rest of the traits are described in the text.

The vigor of the trees or shrubs was evaluated by

Table 7. Trait associations among characters in 10 *P. eurycarpa* genotypes.

	Leaf width	Terminal leaf length	Terminal leaf width	Leaf petiole length	Number of leaflet pairs	Nut weight	Nut thickness	Nut width	Nut length
Leaf length	0.795***	0.376**	0.519***	0.456***	− 0.232	0.261	0.084	0.031	0.591***
Leaf width		0.396**	0.356*	0.478***	0.144	0.233	0.064	0.072	0.492***
Terminal leaf length			0.565***	0.271	− 0.413**	0.233	0.057	0.026	0.396**
Terminal leaf width				0.291*	− 0.444**	0.506***	0.265	0.196	0.732***
Leaf petiole length					− 0.341*	0.384**	0.204	0.164	0.537***
Number of leaflet pairs						− 0.450**	− 0.380**	− 0.174	− 0.307*
Nut weight							0.858***	0.736***	0.713***
Nut thickness								0.839***	0.373**
Nut width									0.286*

* Significant at the 0.05 level; **Significant at the 0.01 level; *** Significant at the 0.001 level.

Table 8. Characteristics of 30 representative *Pistacia* genotypes out of 65 based on phenotypic and morphological traits.

Genotype code	Tree vigor	Growth habit	Branching habit	Leaf color	Leaf indumentum	Resin smell	Terminal leaflet size	Petiole shape	leaflet shape	T. leaflet shape	T. leaflet apex shape	Nut shape
01*-T+-01	low	shrub	dense	G	glabrous	S	smaller	rounded	NE	E	mucronate	obovoid
09-T-01	low	shrub	M	G	glabrous	S	similar	rounded	E	E	acute	obov-glob
09-T-02	low	shrub	M	G	glabrous	S	smaller	rounded	E	OO	retuse	obovoid
09-T-03	low	shrub	M	G	glabrous	S	similar	rounded	NE	NE	acute	obovoid
45-T-01	low	branched	M	G	glabrous	S	bigger	rounded	NE	E	acumunate	obovoid
45-T-03	low	shrub	M	G	glabrous	S	similar	rounded	NE	E	acumunate	obovoid
45-T-04	low	single	M	LG	glabrous	S	smaller	rounded	NE	NE	emarginate	obov-glob
45-T-05	low	shrub	dense	G	glabrous	S	similar	rounded	NE	NE	mucronate	globular
01-A-02	M	single	M	DG	puberulent	M	similar	flattened	NE	E	mucronulate	obovoid
01-A-04	low	single	sparse	DG	puberulent	W	similar	flattened	L	L	acute	globular
09-A-07	low	single	M	DG	puberulent	W	similar	flattened	L	L	acute	obov-glob
09-A-16	M	branched	M	DG	puberulent	W	similar	flattened	L	L	acute	globular
09-A-17	M	branched	M	DG	puberulent	W	similar	flattened	NE	L	acute	globular
45-A-04	high	single	sparse	DG	puberulent	M	smaller	flattened	NE	L	mucronulate	globular
45-A-06	high	single	dense	G	puberulent	W	smaller	flattened	E	O	obtuse	globular
45-A-07	high	single	dense	G	puberulent	M	smaller	flattened	NE	L	mucronulate	globular
45-A-08	high	single	M	G	puberulent	M	bigger	flattened	NE	NE	obtuse	globular
45-A-12	high	single	sparse	G	puberulent	M	smaller	flattened	NE	L	acute	obov-glob
45-A-13	high	branched	M	DG	puberulent	M	similar	flattened	NE	L	acute	globular
45-A-14	M	branched	M	DG	puberulent	M	similar	flattened	L	NE	obtuse	globular
45-A-16	M	single	M	G	puberulent	W	similar	flattened	NE	NE	acute	globular
45-A-18	M	single	M	DG	puberulent	W	similar	flattened	L	L	acute	globular
27-K-01	M	single	dense	G	glabrous	S	bigger	rounded	OO	OO	acute	obovoid
27-K-02	M	single	dense	G	glabrous	S	bigger	rounded	OO	O	mucronulate	obovoid
56-K-01	M	single	dense	LG	puberulent	M	bigger	angled	O	O	mucronulate	glob-comp
56-K-03	high	single	dense	LG	puberulent	M	bigger	angled	O	O	acute	glob-comp
56-K-04	high	single	M	LG	puberulent	M	bigger	angled	O	O	mucronulate	glob-comp
56-K-06	high	single	dense	LG	puberulent	M	bigger	angled	O	OO	acute	glob-comp
56-K-07	high	single	M	LG	puberulent	M	bigger	angled	OO	O	mucronulate	glob-comp
56-K-08	M	single	M	LG	puberulent	M	bigger	rounded	O	OO	acute	glob-comp

* Province codes: (01) Adana, (09) Aydin, (27) Gaziantep, (45) Manisa, (56) Siirt.+ Species codes: (T) *P. terebinthus*, (A) *P. atlantica*, (K) *P. eurycarpa*. M: intermediate, LG: light green, G: green, DG: dark green, S: strong, W: weak, NE: narrow-elliptical, E: elliptical, L: lanceolate, O: ovate, OO: ovate-oblong, obov-glob: obovoid-globular, glob-comp: globular-compressed.

direct observation according to the tree/shrub size, and to the shoot production and elongation in a year. The vigor of all *P. terebinthus* trees and of 01-A-04 and 09-A-07 *P. atlantica* genotypes was lower, whereas the other genotypes had intermediate or high tree vigor. All *P. terebinthus* genotypes from Aydin and Adana provinces as well as 45-T-03 and 45-T-05 genotypes from Manisa grew as shrubs, whereas the remaining *P. terebinthus* genotypes grew as branched or a single tree. *P. atlantica* genotypes 09-A-16, 09-A-17, 45-A-13 and 45-A-14 had a branched growth habit, whereas the remaining *P. atlantica* and all of the *P. eurycarpa* genotypes grew as trees with a single trunk. Genotypes 45-A-02, 45-A-04 and 45-A-12 had a sparse branching habit, whereas the other genotypes showed intermediate or dense branching habits. All genotypes were deciduous.

The trees described as *P. terebinthus* in California were strong and large (D.E. Parfitt, personal communication), however in our survey as well as in the literature *P. terebinthus* trees grew as shrubs or small trees. It is possible that the differences in species description by different authors may be due to age-related variation among trees or to ecological factors.

Leaf rachis wing was absent in all *P. terebinthus* genotypes, and in *P. eurycarpa* genotypes 27-K-01, 27-K-02 and 56-K-01, whereas it was present in all the other genotypes. When present leaf rachis wing was very narrow in *P. eurycarpa* genotypes, especially in the terminal leaflet petiole, and between the terminal leaflet petiole and the former leaflets. The leaf rachis wing of *P. atlantica* genotypes extended along the whole rachis. According to Whitehouse (1957), *P. terebinthus* has narrow leaf rachis wing.

None of *P. terebinthus* genotypes in our survey had leaf rachis wing even as a trace. *P. terebinthus* species may have been, therefore, mis-identified in California. Ayfer and Serr (1961) reported, in fact, that the trees known as a *P. terebinthus* in California may be a variety of *P. atlantica*, because of their high vigor and the leaf rachis wing.

Leaf color was dark green in *P. atlantica*, except for 09-A-13, 45-A-06, 45-A-07, 45-A-08, 45-A-12, 45-A-16, 45-A-19 genotypes whose leaves are lighter. *P. terebinthus* and *P. eurycarpa* had green or light green leaves. So, within the three species, *P. atlantica* had the darkest leaves. Leaf indumentum was glabrous in *P. terebinthus*, whereas it was puberulent in *P. eurycarpa* and *P. atlantica*, an agreement with the literature (Zohary 1952). Genotypes 27-K-01 and 27-K-02 exhibited glabrous leaf indumentum, unlikely the other *P. eurycarpa* genotypes.

A typical resin smell is released when *Pistacia* leaves are crushed. Resin-like smell was strong in *P. terebinthus*, as well as in *P. eurycarpa* genotypes 27-K-01 and 27-K-02, whereas it was intermediate, or weak, in the other *P. eurycarpa* genotypes. All *P. atlantica* genotypes from Aydin province had a weak resin smell, whereas those from Adana and Manisa had weak or intermediate resin smell. In spite of a few exceptions, this character seemed therefore to be a good diagnostic character between the three species.

Leaf waxiness was determined by comparing leaf samples in this experiment with *P. lentiscus* L. leaves, which are waxy. Moreover, wax-less leaves display clear veins (El-Oqlah 1996). However, all the genotypes in our study had no wax on their leaves. All genotypes had a leaf petiole in agreement with the literature (Zohary 1952, 1972; Yaltirik 1967), and the leaflets of all *Pistacia* genotypes surveyed were sessile.

Absence or presence of a terminal leaflet is important in distinguishing *Pistacia* species. Some of *Pistacia* species (*P. vera*, *P. atlantica*) have imparipinnate leaves and several of them (*P. lentiscus*, *P. chinensis* Bge) have paripinnate leaves. In the latter group, the paripinnate leaf is always predominant but the lowest and uppermost leaves of the shoots are often imparipinnate (Zohary 1952). In the current study, median leaves in a shoot were characterized, and all the *Pistacia* genotypes, however, had mainly imparipinnate leaves, some *P. terebinthus* genotypes had paripinnate leaves as well, representing approximately 10–30% of their leaves. In addition, some *P. atlantica* genotypes also had (very rarely) paripinnate leaves, while *P. eurycarpa* leaves were exclusively imparipinnate. A mixture of paripinnate and imparipinnate leaves in the same tree may represent natural variation in this trait. In any case, because of such unexplained variation, this character should not be taken as a major character to distinguish *Pistacia* species.

Yaltirik (1967) reported that *P. terebinthus* had either imparipinnate or paripinnate leaves and therefore, he described two subspecies within *P. terebinthus*. The first, *P. terebinthus* subsp. *terebinthus*, had imparipinnate leaves with the terminal leaflet of the median leaves often as large as the lateral ones, and obtuse or ovate-oblong lateral leaflets. The second is *P. terebinthus* subsp. *palaestina* (Boiss.) Engl. with paripinnate leaves (rarely imparipinnate), the terminal leaflet of the median leaves always smaller than the laterals or reduced to a bristle, and acuminate or oblong-lanceolate lateral leaflets. Zohary (1952), however, considered *P. palaestina* Boiss. as a distinct species, due to two main distinctive characteristics. *P. palaestina* has mostly paripinnate leaves and acuminate leaflets, while *P. terebinthus* has imparipinnate leaves and obtuse or acute leaflets. Kafkas and Perl-Treves (2001a) performed a study on inter-specific relationships of nine *Pistacia* species at molecular level, and suggested that *P. terebinthus* and *P. palaestina* should be considered as a same species. According to our morphological data, it is difficult to classify our *P. terebinthus* genotypes at the infraspecific level. Therefore, a molecular study using DNA markers is needed to explain such classification which have been already performed using RAPD markers by Kafkas and Perl-Treves (2001b) that did not relate with morphological data. As a result, we retain our *P. terebinthus* genotypes without infraspecific classification, as *P. terebinthus*.

Terminal leaflet was generally similar in size, or smaller than the basal leaflets in *P. terebinthus*, except for genotype 45-T-01 that had a bigger terminal leaflet. Terminal leaflet size of most *P. atlantica* genotypes was also similar to the lateral ones, in most genotypes but several exceptions with either larger or smaller terminal leaflets were observed. *P. eurycarpa* genotypes mostly had terminal leaflets that were similar or bigger than the basal ones. The ratio between the terminal and basal leaflets of *P. terebinthus* and *P. eurycarpa* genotypes in this study were similar to previous reports (Zohary 1952, 1972; Yaltirik 1967).

Leaflet shapes of *P. terebinthus* genotypes were either narrow-elliptical or elliptical. *P. atlantica* genotypes from Adana province had lanceolate leaflets except for 01-A-02 (narrow-elliptical). *P. atlantica* genotypes from Aydin and Manisa provinces had lanceolate or narrow-elliptical leaflets except for 45-A-06 genotype (elliptical). *P. eurycarpa* genotypes had ovate or ovate-oblong leaflet shapes. Terminal leaflet shape is a diagnostic character and may vary within and between the species. In most genotypes the shape is similar to that of the other basal leaflets.

Terminal leaflet apex is an important differential characters within and between *Pistacia* species (Zohary 1952). Terminal leaflet apex shape varied, and was mucronate, acute, retuse, acuminate or emerginate in different *P. terebinthus* genotypes. It was obtuse, mucronulate or acute in *P. atlantica* genotypes, and mucronulate or acute in *P. eurycarpa* genotypes. However, the shape of the terminal leaflet apex varied also within the same tree. Variability was sometimes observed even within a leaf. Therefore, we only indicated the predominant character for each genotype, and we concluded that this trait should not be taken as a diagnostic character for *Pistacia* species as in the literature.

The shape of the leaf petiole cross-section was rounded in all *P. terebinthus* genotypes. It was angled in the majority of *P. eurycarpa* genotypes except of genotypes 56-K-08, 27-K-01 and 27-K-02 that had a rounded petiole, and it was flattened in all *P. atlantica* genotypes, in agreement with previous studies (Zohary 1952, 1972; Yaltirik 1967).

P. terebinthus nuts were slightly tipped, whereas there was no tip in the nuts of *P. atlantica* and *P. eurycarpa*. Hull consistency refers to the texture of the hull, that may be either fleshy-juice or fleshy-dry at maturity. In our survey, hull consistency was fleshy-dry in all *Pistacia* genotypes, as reported in the literature (Zohary 1952).

Nut shape ranged between obovoid, obovoid-globular or rarely globular in *P. terebinthus*. Nuts were globular, obovoid-globular or occasionally obovoid in *P. atlantica*, and globular and somewhat compressed in *P. eurycarpa* except for 27-K-01 and 27-K-02 genotypes that have obovoid nut shapes.

In conclusion, some of the quantitative and qualitative characters surveyed were found to be more useful than others in distinguishing the species: growth habit, several leaf traits (leaf size, leaf rachis wing, number of leaflet pairs, leaf petiole shape, leaf petiole length, resin smell, leaf color) and nut characters (nut weight, nut sizes and nut shape) were rather useful as descriptors for species classification.

Genotypes 27-K-01 and 27-K-02 differed from the other *P. eurycarpa* genotypes in some leaf and nut characters. Their leaf size was bigger and their leaf indumentum was glabrous, whereas it was puberulent in the other genotypes, their resin smell was stronger, their nut shape was obovoid and never compressed, whereas it was globular compressed in the other *P. eurycarpa* genotypes. Therefore, we suggest that they represent a hybrid between *P. eurycarpa* and *P. vera*, since their leaf and nut shapes, leaf indumentum, resin smell and lack of rachis wing characters were similar to *P. vera* (Zohary 1952, 1972; Yaltirik 1967). The 56-K-08 genotype was also assumed to be a *P. vera* hybrid. Its nuts were heavier and larger than those of the other *P. eurycarpa* genotypes.

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