Genet Resour Crop Evol (2009) 56:561–571
DOI 10.1007/s10722-008-9386-y

RESEARCH ARTICLE

Morphological diversity of *Pistacia* species in Iran

H. R. Karimi · Z. Zamani · A. Ebadi · M. R. Fatahi

Received: 27 February 2008 / Accepted: 4 November 2008 / Published online: 6 December 2008

Abstract Pistachio is one of the most important horticultural crops in Iran. Selection of suitable genotypes, resistant to unfavorable environmental and soil conditions and diseases, are important for increasing yield efficiency and the acreage of this important crop. The aim of this research was to evaluate wild pistachio species and genotypes native to Iran and also to determine any relationships that exist according to their phenotypical characteristics. A total of 11 pistachio types *in situ* from Kerman and Fars provinces and *ex situ* from the Iranian Pistachio Research Institute (IPRI) were used during the research. Thirty-one morphological characteristics (17 quantitative and 14 qualitative) were evaluated based on the pistachio descriptor (IPGRI). Results from simple correlation analyses showed significant positive and negative correlations in certain important characteristics. Nut thickness and weight were in significant correlation with the size (dimensions) of the leaves and terminal leaflets. Factor analysis was used to determine the effective characteristics and the number of main factors. For each factor loading a value of more than 0.65 was judged as being significant. Effective characteristics were categorized into seven main factors that contributed to 94% of the overall variance. Leaf and nut characteristics were defined mainly by the first factor contributing to 40% of the total variance. Pistachio genotypes were clustered based on seven factors and at a similarity distance of 10, these were further divided into three sub-clusters each consisting of genotypes belonging to species *P. vera* L., *P. khinjuk* Stocks. and *P. atlantica* Desf. Based on the results, *P. khinjuk* was located between the other two species, but resembled *P. atlantica* more than *P. vera*.

Keywords Genotype · *Pistacia atlantica* Desf. · *P. khinjuk* Stocks. · *P. vera* L.

Introduction

The genus *Pistacia* in the Anacardiaceae family contains 13 or more species, among which *Pistacia vera* L. produces commercially valuable edible nuts. The other species grow in the wild and their seedlings are used mainly as rootstocks for pistachios (Kafkas et al. 2002a). There are two main centers of diversity for *Pistacia*: one comprises the Mediterranean region of Europe, Northern Africa and the Middle Eastern countries. The second is the Eastern part of Zagros

H. R. Karimi (✉) · Z. Zamani · A. Ebadi · M. R. Fatahi
Department of Horticultural Science, College of Agriculture, University of Tehran, Karaj 31587-11167, Iran
e-mail: h_karimi214@yahoo.com

H. R. Karimi
Department of Horticultural Science, College of Agriculture, Vali-e-Asr University, Rafsanjan, Kerman, Iran

Mountains and Caucasus region ranging from Crimea to the Caspian Sea (Zohary 1952).

In the first monograph study of *Pistacia* species, Engler (1881) listed eight species and a few subspecies, however he did not suggest any sectional subdivisions for such species and some species were not fully described by him (Zohary 1952). So far the most comprehensive taxonomic study of the *Pistacia* genus was reported by Zohary (1952), who divided the genus into four sections and 11 species according to leaf characters and nut morphology. However, he found no justification in retaining *mutica* (Fisch. et C. A. Mey.) Rech. f. and *cabulica* (Stocks) Rech. f. as species or subspecies. Kafkas and Perl-Treves (2001) characterized *Pistacia* species in Turkey by morphological and molecular data. They revised the miss-identification of a sample as *P. eurycarpa* Yalt. that was previously described by Yaltirik (1967) as *P. khinjuk*. Recently two monophyletic groups have been proposed in this genus by using cpDNA, *Terebinthus* and *Lentiscus*, representing deciduous and evergreen species respectively (Parfitt and Badenes 1997). Three important wild *Pistacia* species including *P. vera*, *P. khinjuk* and *P. atlantica* grow in Iran. Forests of wild *P. vera* spread to an area of about 75,000 ha, in central Asia, near the boarders of Turkmenistan, Afghanistan and Northeast of Iran. In Iran *P. vera* grows predominantly in the Sarakhs region covering roughly 17,500 ha (Behboodi 2003).

The *atlantica* species has been postulated to have three subspecies in Iran, *mutica*, *kurdica* (Zoh.) Rech. f. and *cabulica* (Rechinger 1963). Zohary (1952) described *P. atlantica* as comprising of two subspecies (*kurdica*, *latifolia* DC.) and he did not find any justification in retaining *P. mutica* and *P. cabulica* as either a species or subspecies and thought instead they should be considered as *P. atlantica* Desf. subsp. *latifolia* DC. Zohary (1972) later suggested *P. atlantica* to be as an Irano-Turanian species with three subspecies; Asiatic (subsp. *cabulica*), Mediterranean (subsp. *atlantica*) and Asiatic-Mediterranean (subsp. *mutica*).

P. atlantica Desf. subsp. *mutica* (Fisch. et C. A. Mey.) Rech. f. is a highly resistant rootstock to root-knot nematodes compared with *P. vera, P. palestina* Boiss. and *P. khinjuk* (Farivar-Mehin 1995).

P. atlantica subsp. *kurdica* (Zoh.) Rech. f. is mainly centered in Iran and Afghanistan, overlapping with *P. vera* in some areas. The subspecies *cabulica* is more tolerant in comparison to other *P. atlantica* subspecies, to exothermic and warm weather conditions. It has been suggested that this subspecies or its hybrids could be used as rootstocks to improve domestic pistachio production (Behboodi 2003). *P. khinjuk* trees are widely distributed at elevations ranging from 700 to 2000 m on hills and mid-height mountains (Behboodi 2003). Although able to withstand some of the most inconvenient weather conditions it is nevertheless sensitive to the fungus *Phytophthora* spp. (Banihashemi 1995) but has moderate resistance to root-knot nematodes (Farivar-Mehin 1995).

Leaf characteristics and nut morphology are the main diagnostic traits used in distinguishing various species of *Pistacia*. Flower characteristics have been less widely used for characterization of *Pistacia* species except at the genus and higher levels. Wood anatomy has also been used as a tool in identification (Grundwag and Werker 1976).

Yaltirik (1967) classified *Pistacia* species in Turkey and introduced *P. eurycarpa* as a new species. Kafkas et al. (2002b) studied the morphological diversity of wild *Pistacia* species in Turkey and found that nut weight and width was in significant correlation with the terminal leaflet lengths in *P. terebinthus* L. and *P. atlantica*. It was also reported that the width and length of the terminal leaflets were in negative correlation with the number of leaflets present. Upon examining *P. terebinthus* it was showed that leaf length was in significant correlation with the number of leaflets present.

Modern objectives in plant breeding may be achieved by the evaluation of traits amongst genetic resources and combining those of interest in one cultivar. Although new methods of molecular markers for genotype description have been proved useful, these methods are however expensive. Morphological characters must be recorded for selection of parents and are also the first choice used for describing and classifying the germplasm. Statistical methods including principle components or cluster analysis can be used as useful tools for screening the accessions. Additionally, morphological characteristics sometimes correlate or are associated with characteristics that are difficult to evaluate such as disease susceptibility and therefore may be useful as markers in breeding programs.

The study undertaken aimed to establish if any morphological relationships existed between 11 types of wild and cultivated pistachios in Iran that are mainly used as rootstocks. The results achieved could be positively applied in the characterization of pistachio species and in breeding programs.

Materials and methods

A total of 11 *Pistacia* types, each comprising three samples, growing *in situ* from Kerman and Fars provinces and *ex situ* from the Iranian Pistachio Research Institute (IPRI) were labeled to enable recording of their morphological specifications. The areas for *in situ* collection were selected according to Rechinger (1963). The genotypes were described based on the *Pistacia* descriptor developed by the International Plant Genetic Resources Institute (IPGRI 1998) with minor modifications. Each type (species or subspecies) comprised of three replicated samples. One type was unidentifiable and labeled as unknown. Thirty one characteristics (17 quantitative and 14 qualitative) were identified for evaluating the chosen samples (Tables 1, 2). Ten rachises were harvested of each tree to measure the rachis length and the number of fruits per rachis. The flower buds were dried and then soaked in water for 12 h to allow the bud scales to separate to enable counting of the number of scales in the flower buds. Ten fully developed leaves were removed from each tree to evaluate the characteristics of the leaves and leaflets. The shape of the terminal leaflet, terminal leaflet apex, terminal leaflet base, and the nut shape were scored according to the descriptor. One hundred nuts per tree were randomly selected to measure their weight and dimensions. Analysis of variance, means comparison, simple correlations, factor and cluster analysis were carried out using SPSS and SAS software to reveal the relationships between the genotypes.

Results

Analysis of variance

Significant differences ($P \leq 0.05$) were detected among the species for all the noted characteristics by analysis of the variance. Leaf length, terminal leaflet length and nut characteristics such as nut length and width were significantly different between *P. atlantica* and the other species. However, there were no differences between three subspecies of *P. atlantica* from Iran for the afore mentioned characteristics apart from nut length. Also *P. khinjuk* was significantly different in comparison to other species in nut

Table 1 The list of qualitative traits of Pistachios and their classification according to IPGRI descriptor

Traits	Abbreviation	Character states and their code				
		1	2	3	4	5
Growth habit of tree	GRHT	Erect	Semi-erect	Spreading		
Trunk color	TRKC	White	Grey brownish	Grey		
Current year shoot color	CYSC	Light brown	Brown	Dark brown		
Terminal leaflet size	TLSZ	Smaller	Similar	Bigger		
Terminal leaflet shape	TLSH	Lanceolate	Ovate	Elliptic	Narrow elliptic	Roundish
Terminal leaflet apex shape	TLAS	Mucronulate	Acuminate	Mucronate	Acute	Retuse
Terminal leaflet base shape	TLBS	Attenuate	Obtuse	Truncate	Oblique	
Petiole shape	PTS	Flattened	Rounded	Semi-Rounded		
Leaf color	LFC	Light green	Green	Dark green		
Leaf texture	LFT	Leathery	Membranous			
Leaf indumentums	LFI	Absent	present			
Leaf rachis wing	LFRW	Absent	Present in rachis	Present until petiole		
Arrangement of scales in FB[a]	ASFB	Opposite	Spiral	Alternate		
Nut shape	NUS	Cordate	Obovid Obovid tail	Globular depressed	Globular	Roundish

[a] *FB* Flower bud

Table 2 Pistachio genotypes used for morphological classification and their measured quantitative characteristics

No	Genotype	Species	Location	Leaf length (cm)	Leaf width (cm)	No of leaflets	Terminal leaflet length (cm)	Terminal leaflet width (cm)	Nut length (mm)	Nut width (mm)	Nut thickness (mm)
1	KHI1	*P. khinjuk*	IPRR[a]	11.35	10.21	3.4	5.15	5	5.9	4.2	2.7
2	KHI2		IPRR[a]	10.42	8.11	3	4.25	3.41	5.6	5	3.1
3	KHI3		IPRR[a]	10	9	4	4.17	3.48	6.2	4.3	3.2
4	AAI1	*P. atlantica*	IPRR[a]	8.65	7.25	6.4	3.84	1.6	4.5	5.7	5.3
5	AAI2		IPRR[a]	8.72	6.64	7	3.38	1.42	5.5	6.1	5.1
6	AAI3		IPRR[a]	8.68	6.94	6.7	3.61	1.51	5	6.2	4.6
7	AMI1	*P. atlantica* subsp. *mutica*	IPRR[a]	11.71	8.1	6	4.35	2.37	6	7.8	5.3
8	AMI2		IPRR[a]	10.29	10.62	5.6	5.45	2.31	6.2	8.1	5.1
9	AMI3		IPRR[a]	12.48	8.37	6.2	4.33	2.39	6.4	8.1	5.2
10	BBI1	Hybrid	IPRR[a]	12	9.87	4.6	4.52	2.9	8	8.7	5.4
11	BBI2		IPRR[a]	11.4	9	6.6	4.38	2.16	7.5	9.2	5.1
12	BBI3		IPRR[a]	12	10.2	5	5.56	2	8.5	9.1	5.3
13	BDI1	*P. vera*	IPRR[a]	14.9	14.8	3	9.5	5.2	20	9	9.1
14	BDI2		IPRR[a]	14.5	15.6	3	10.3	5	18	10	9.5
15	BDI3		IPRR[a]	14.6	15.6	4	9.1	4.95	16	11	9.3
16	QZI1		IPRR[a]	14.4	14.15	4.4	8.25	4.65	19	10	9.6
17	QZI2		IPRR[a]	12.7	14.9	4.2	8.3	4.85	17	8	9.7
18	QZI3		IPRR[a]	8.82	12.25	5	7.56	4.45	18	12	9.8
19	SRI1		IPRR[a]	15.4	11.7	4.4	6.66	3.84	14	11	8.3
20	SRI2		IPRR[a]	16	16	4.8	7.9	4.96	12	10.2	7.8
21	SRI3		IPRR[a]	12.7	14.75	4.6	7.9	4.71	13	10.3	8.2
22	AKF1	*P. atlantica* subsp. *kurdica*	Fars	13.97	9.74	6.2	6	1.98	6.2	8	8.7
23	AKF2		Fars	15	11.94	7	5.37	2.53	5.9	6.5	8.1
24	AKF3		Fars	13.7	10.83	6.8	6.1	2.38	6.5	7.3	8.4
25	AKK1		Kerman	13.92	12.62	5	6.1	3.33	7.3	7.3	4.1
26	AKK2		Kerman	13.33	10	6.4	5.22	3.14	7	7.1	4.3
27	AKK3		Kerman	15.87	12.65	6.6	5.63	3.24	7.15	7.2	4.5
28	ACF1	*P. atlantica* subsp. *cabulica*	Fars	17.59	12.95	6.8	6	2.28	7.5	7.3	5
29	ACF2		Fars	14.88	11.71	7.2	5.85	2.26	7.3	7.2	4.9
30	ACF3		Fars	16.23	12.33	7	5.93	2.27	7.7	6.5	5.3
31	UNK1	Unknown	Kerman	12.55	9.76	5	5.16	1.95	6.5	6.3	4.5
32	UNK2		Kerman	10.36	9.87	5.25	5.57	2.1	7.5	8.3	5
33	UNK3		Kerman	13.98	9.63	6.6	4.93	2.03	7	7.3	4.7

[a] Obtained from the Iran Pistachio Research Institute (IPRI)

characteristics and number of fruits per rachis (Table 3). Mean values of the studied morphological characteristics showed large variations between the genotypes for all of the measured traits. Mean values and the range of variability for the different characteristics of each genotype are presented in Table 4. *P. vera* was shown to have the heaviest nuts and the largest nut dimensions, whereas *P. khinjuk* were found to be the lightest nut examined (Table 2). Also the number of leaflets was least amongst *P. vera* and *P. khinjuk* and most in *P. atlantica*. The largest dimensions of leaves and leaflets in *P. atlantica* were found in those growing in Fars province and least for those in found in Kerman province.

Table 3 Means comparison of quantitative traits in different *Pistacia* genotypes

Genotypes	Traits														
	LFL	LFW	TLFL	TLFW	TLFL/W	NLF	TLFPL	FBL	FBW	RAL	NFPR	NUL	NUW	NUT	SNUP	100NUDW
KHI	10.59 ef	9.1 f	4.52 e	3.96 b	1.47 e	3.46 e	1.73 a	6.3 g	5.0 abc	9.63 ab	70.4 a	5.9 g	4.5 f	3.0 i	0.0 d	3.3 j
AAI	8.68 f	6.94 g	3.61 f	1.51e	2.4 abc	6.7 ab	0.3 g	6 h	4 c	6.88 dc	53.2 b	5 h	6 e	5 f	0.0 d	105 I
AMI	11.49 de	9.03 f	4.71 de	2.35 d	1.99 cde	5.93 bc	0.69 de	8.2 c	4.3 bc	8.34 abcd	40.66 bc	6.2 f	8.0 c	5.2 f	0.0 d	15.3 e
BBI	11.8 cde	9.69 ef	4.82 de	2.35 d	2.11 bcd	5.4 cd	0.93 cd	6.0 h	4.0 c	8.65 abc	30.0 cd	8.0 c	9.0 b	6.0 e	0.0 d	21.0 d
BDI	14.66 ab	15.33 a	9.63 a	5.05 a	1.91 cde	3.33 e	1.39 b	7.1 e	5.5 abc	7.88 bcd	28.33 cd	18 a	10 a	9.3 b	90 a	82 a
QZI	12.99 bcde	13.76 abc	8.03 b	4.65 ab	1.72 de	4.5 d	1.14 c	6.6 f	5.6 ab	6.57 d	40.46 bc	18 a	10 a	9.7 a	88 b	69 b
SRI	14.7 ab	14.15 ab	4.48 b	4.5 ab	1.66 de	4.6 d	0.92 cd	8.0 c	5.1 abc	9.06 ab	31.76 cd	13.0 b	10.5 a	8.1 d	10.0 c	48.0 c
AKF	14.21 abcd	10.83 def	5.52 cd	2.29 d	2.41 abc	6.66 ab	0.28 g	8.5 b	4.6 abc	9.0 ab	38.4 bc	6.2 f	7.2 d	8.4 c	0.0 d	15.3 e
AKK	14.37 abc	11.75 cde	5.65 cd	3.23 c	1.74 de	6 bc	0.58 ef	9 a	5.5 abc	9.18 ab	28 cd	7.15 e	7.2 d	4.3 h	0.0 d	12 g
ACF	16.23 a	12.33 bcd	5.92 c	2.27 d	2.6 ab	7 a	0.0 h	9.2 a	4 c	10.12 a	41.25 bc	7.5 d	7 d	5.1 f	0.0 d	14.5 f
UNK	12.29 bcde	9.72 ef	5.22 cde	2.02 de	2.7 a	5.61 c	0.36 fg	7.6 d	6 a	8.03 bcd	19.16 d	7 e	7.3 d	4.75 g	0.0 d	11.3 h

Similar letters in each column are not statistically different at 5% level of probability using Duncan multiple range test (DMRT)

Genotypes and trait abbreviations taken from Tables 2 and 4

Correlations

The correlation between each pair of traits was calculated (Table 5). It was found that several leaf characteristics were in significant correlation with nut characteristics. Nut characteristics such as length ($r = +0.80$), width ($r = +0.67$), thickness ($r = +0.66$) and weight ($r = +0.77$) positively correlated with the width of the leaves. Also nut thickness ($r = +0.51$), nut width ($r = +0.50$) and nut length ($r = +0.81$) were in significant correlation with the width of the terminal leaflet. Leaflet characteristics, terminal leaflet width ($r = -0.78$) and terminal leaflet length ($r = -0.54$), were in negative correlation with the number of leaflets.

In *P. vera* split nut percentage correlated with width of the leaf ($r = +0.65$), terminal leaflet length ($r = +0.82$), terminal leaflet width ($r = +0.72$), nut length ($r = +0.93$), nut width ($r = +0.60$), nut thickness ($r = +0.75$) and nut weight ($r = +0.93$). Also split nut percentage was in negative correlation with the number of leaflets ($r = -0.55$).

Factor analysis

Factor analysis was used to determine the number of main factors for reducing the number of effective characteristics to discriminate genotypes (Table 6). Based on factor analysis the characteristics of leaves and nuts accounted for 40% of the variance as the first main factor with the other six factors, explaining 94% of the total variance. For each factor, a factor loading of more than 0.65 was considered as being significant. For the first factor, characteristics including leaf width, length of terminal leaflet, nut length, nut width, nut thickness, one hundred nuts dry weight and split nut percentage had a loading of more than 0.65 and defined 40% of the overall variance. The width of the terminal leaflet, petiole length of terminal leaflet, terminal leaflet base shape, terminal leaflet size, number of leaflets, arrangement of scales in flower bud, flower bud width and leaf rachis wing were significant for the second factor with 20.42% of overall variance. The third factor with 13.52% of the overall variance contributed to characteristics such as rachis length, leaf length, number of scales in the flower bud and flower bud length. The remaining factors were leaf texture (4th factor), petiole shape

Table 4 Pistachio characteristics, range of variability, mean and coefficient of variations for qualitative and quantitative traits

No	Trait	Abbreviation	Unit	Mean	Min	Max	CV (%)[a]
1	Growth habit of tree	GRHT	1–3	–	1	3	–
2	Trunk color	TRKC	1–3	–	1	3	–
3	Leaf length	LFL	cm	12.91	8.65	17.59	5.12
4	Leaf width	LFW	cm	11.15	6.64	16	6.96
5	Terminal leaflet length	TLFL	cm	5.92	3.38	10.3	7.78
6	Terminal leaflet width	TLFW	cm	3.11	1.51	5.2	11.89
7	Terminal leaflet length/width	TLFL/W	ratio	2.06	1	2.97	5.82
8	Terminal leaflet size	TLSZ	1–3	–	1	3	–
9	Terminal leaflet shape	TLSH	1–5	–	1	5	–
10	Terminal leaflet apex shape	TLAS	1–5	–	1	5	–
11	Terminal leaflet base shape	TLBS	1–4	–	1	4	–
12	Leaf color	LFC	1–3	–	1	3	–
13	Number of leaflets	NLF	–	5.38	3.00	7.20	
14	Leaf texture	LFT	1–2	–	1	2	–
15	Leaf indumentum	LFI	–	–	–	–	–
16	Terminal leaflet petiole length	TLFPL	mm	0.76	0	1.90	21.00
17	Leaf rachis wing	LFRW	1–3	–	1	3	–
18	Petiole shape	PTS	1–3	–	1	3	–
19	Current year shoot color	CYSC	1–3	–	1	3	–
20	Arrangement of scales in flower bud	ASFB	1–3	–	1	3	–
21	Number of scales in flower bud	NSFB	–	13.98	10.00	20.00	8.20
22	Flower bud length	FBL	mm	7.52	6.00	9.20	4.65
23	Flower bud width	FBW	mm	4.73	4.00	5.60	4.04
24	Rachis length	RAL	cm	8.49	5.66	10.25	4.9
25	Number of fruits per rachis	NFPR	–	38.33	14.40	90.00	11.32
26	Nut length	NUL	mm	9.26	4.50	20.00	15.73
27	Nut width	NUW	mm	7.88	4.30	10.30	7.25
28	Nut thickness	NUT	mm	6.25	2.70	9.80	10.77
29	Nut shape	NUS	1–5	–	1	5	–
30	Split nuts percentage	SNUP	%	17	0	90.00	62.94
31	100 Nut dry weight	100NUDW	g	27.55	3.30	82.00	45.54

[a] *CV* Coefficient of variation = (Standard error/Mean) × 100

and nut shape (5th factor), growth habit (6th factor) and trunk color (7th factor).

The pistachio genotypes were grouped according to these seven factors. Cluster analysis divided accessions into three sub-clusters each consisting of genotypes belonging to the species *P. vera*, *P. khinjuk* and *P. atlantica*. Based on the results, *P. khinjuk* was found to be an in-between species, but more resembled *P. atlantica* than *P. vera*. *P. atlantica*, with *P. atlantica* subsp. *mutica* was located in the same group while *P. atlantica* subsp. *kurdica* was separated from them. Hybrid accession located between *P. atlantica* subsp. *kurdica* and *P. atlantica* subsp. *mutica* (Fig. 1).

Discussion

Comparison of means showed that there were significant differences between *P. atlantica* and other species for many leaf and nut traits. In similar studies, Kafkas et al. (2002b) reported that average leaf length, terminal leaflet length and width, leaf petiole

Table 5 Bivariate correlations among quantitative and qualitative traits in pistachio genotypes

		1	2	3	4	5	6	7	8	9	10
1	LFL	1.00									
2	LFW	0.67**	1.00								
3	TLFL	0.54**	0.93**	1.00							
4	TLFW	0.33	0.77**	0.80**	1.00						
5	TLFPL	−0.16	0.26	0.36*	0.74**	1.00					
6	NLF	0.08	−0.41*	−0.54**	−0.78**	0.9**	1.00				
7	TLBS	0.12	0.47**	0.50**	0.73**	0.56**	−0.58**	1.00			
8	TLFS	−0.15	0.18	0.31	0.55**	0.72**	−0.72**	0.47**	1.00		
9	PTS	0.27	0.17	0.21	−0.05	−0.05	0.02	−0.12	−0.7**	1.00	
10	LFC	0.37*	0.49**	0.42*	0.44*	0.16	−0.14	0.27	0.058	−0.18	1.00
11	LFRW	−0.08	−0.43*	−0.53**	−0.71**	−0.71**	0.78**	−0.76**	−0.60**	−0.10	−0.26
12	CYSC	−0.05	−0.43*	−0.50**	−0.74**	−0.84**	0.80**	−0.64**	−0.60**	−0.10	−0.43
13	TLFL/W	−0.10	−0.24	−0.24	−0.71**	−0.72**	0.57**	−0.52**	−0.40*	0.27	−0.45**
14	NUL	0.35*	0.80**	0.92**	0.81**	0.48**	−0.58**	0.59**	0.34	0.17	0.37*
15	NUW	0.37*	0.67**	0.73**	0.50**	0.17	−0.28	0.27	−0.04	0.17	0.62**
16	NUT	0.36*	0.66**	0.77**	0.51**	0.15	−0.24	0.41*	0.14	0.22	0.42*
17	100 NUDW	0.32	0.77**	0.91**	0.76**	0.44*	−0.55**	0.49**	0.33	0.15	0.38*
18	NUS	0.24	0.03	−0.13	−0.10	−0.28	0.13	0.10	−0.15	−0.42*	0.20
19	GRHT	0.32	0.49**	0.47**	0.38*	0.06	−0.19	0.56**	0.18	0.11	0.60**
20	SNUP	0.20	0.65**	0.82**	0.72**	0.48**	−0.55**	0.52**	0.40*	0.28	0.17

		11	12	13	14	15	16	17	18	19	20
1	LFL										
2	LFW										
3	TLFL										
4	TLFW										
5	TLFPL										
6	NLF										
7	TLBS										
8	TLFS										
9	PTS										
10	LFC										
11	LFRW	1.00									
12	CYSC	0.84**	1.00								
13	TLFL/W	0.45**	0.61**	1.00							
14	NUL	−0.57**	−0.60**	−0.34	1.00						
15	NUW	−0.38*	−0.50**	−0.18	0.79**	1.00					
16	NUT	−0.34	−0.41*	−0.09	0.81**	0.81**	1.00				
17	100 NUDW	−0.51**	−0.56**	−0.30	0.98**	0.81**	0.85**	1.00			
18	NUS	−0.10	0.13	0.08	−0.29	−0.07	−0.38*	−0.34	1.00		
19	GRHT	−0.57**	−0.43*	−0.15	0.48**	0.57**	0.43*	0.41*	0.36*	1.00	
20	SNUP	−0.49**	−0.49**	−0.28	0.93**	0.60**	0.75**	0.93**	−0.55**	0.31**	1.00

*Significant at 5% prob. **Significant at 1% prob. level

Table 6 Eigen values and cumulative variance for seven major factors obtained from factor analysis and the characteristics within each factor for *Pistacia* genotypes

Factor		1	2	3	4	5	6	7
Cumulative variance (%)		39.99	60.41	73.93	80.53	86.35	90.38	94
Eigen value		12.39	6.33	4.19	2.04	1.80	1.24	1.12
Characteristics	Units	Factor loading						
Rachis length	cm	−0.470	0.169	0.686**	0.376	0.217	−0.172	−0.216
Number of fruits per rachis	–	−0.547	0.227	−0.247	0.07	0.240	−0.677	0.217
Leaf length	cm	0.493	−0.04	0.857**	0.03	0.04	0.07	−0.09
Leaf width	cm	0.824**	0.279	0.458	0.113	0.09	0.08	−0.05
Terminal leaflet length	cm	0.878**	0.359	0.268	0.09	−0.01	0.08	0.09
Terminal leaflet width	cm	0.614	0.664**	0.07	0.327	.225	−0.07	−0.04
Terminal leaflet petiole length	mm	0.188	0.711**	−0.318	0.496	0.05	−0.181	−0.223
Number of leaflets	–	−0.334	−0.766**	0.223	−0.322	−0.08	0.06	0.248
Terminal leaflet shape	–	−0.392	0.07	−0.516	0.216	0.587	−0.368	−0.209
Terminal leaflet apex shape	–	−0.05	0.457	−0.244	0.672	−0.385	−0.07	−0.08
Terminal leaflet base shape	–	0.272	0.776**	0.03	0.103	0.235	0.231	0.04
Terminal leaflet size	–	0.02	0.853**	−0.195	0.07	−0.09	−0.08	−0.06
Leaf indumentums	–	−0.549	0.480	0.261	0.173	−0.151	−0.297	−0.01
Petiole shape	–	0.01	−0.274	−0.163	−0.216	−0.92**	−0.01	0.136
Leaf color	–	0.385	−0.07	0.221	0.640	0.438	0.300	0.188
Current year shoot color	–	−0.314	−0.585	0.154	−0.581	−0.05	−0.209	0.377
Terminal leaflet length/width	–	−0.173	−0.535	0.187	−0.658	−0.395	0.112	0.04
Nut length	mm	0.908**	0.383	−0.03	0.113	−0.05	0.09	−0.01
Nut width	mm	0.853**	−0.124	0.03	0.346	0.03	0.257	−0.08
Nut thickness	mm	0.949**	0.130	−0.134	0.07	−0.05	0.161	−0.03
100 nut dry weight	g	0.929**	0.309	−0.08	0.117	−0.07	0.06	0.03
Nut shape	–	−0.239	−0.08	0.369	−0.247	0.709**	0.355	−0.219
Growth habit	–	0.329	0.273	0.178	0.06	0.230	.819**	0.05
Trunk color	–	0.06	−0.252	0.09	−0.04	−0.312	−0.06	0.876**
Arrangement of scales in flower bud	–	−0.264	−0.673**	0.176	−0.03	0.272	0.104	0.410
Number of scales in flower bud	–	−0.189	−0.295	0.789**	−0.360	0.05	0.212	0.217
Split nuts percent	%	0.803**	0.453	−0.135	0.05	−0.305	0.07	0.166
Flower bud length	mm	0.09	−0.345	0.828**	−0.03	0.200	0.136	0.239
Flower bud width	mm	0.422	0.705**	0.178	0.303	0.195	0.176	0.331
Leaf texture	–	−0.190	−.305	−0.05	−.913**	−0.05	0.09	−0.01
Leaf rachis wing	–	−0.233	−.736**	0.04	−.264	−.100	−0.423	0.174

**Significant factor loadings (considered values above 0.65)

length and all nut characteristics were significantly different between each of the three species *P. terebinthus*, *P. atlantica* and *P. eurycarpa*.

Correlations between quantitative traits of pistachio accessions showed that several leaf characteristics were in significant correlation with nut characteristics. Kafkas et al. (2002b) also reported that nut weight in *P. atlantica* was in significant correlation with terminal leaf length and nut thickness, which is in accordance with the finding of the study carried out. Results showed that split nut percentage correlated with the dimension and weight of the nut. It was deduced that the splitting suture may develop better with increasing the nut dimensions and it seems that the kernel mechanical force is higher in this case. Leaf rachis wing was absent in the *P. vera*, *P. khinjuk* and the

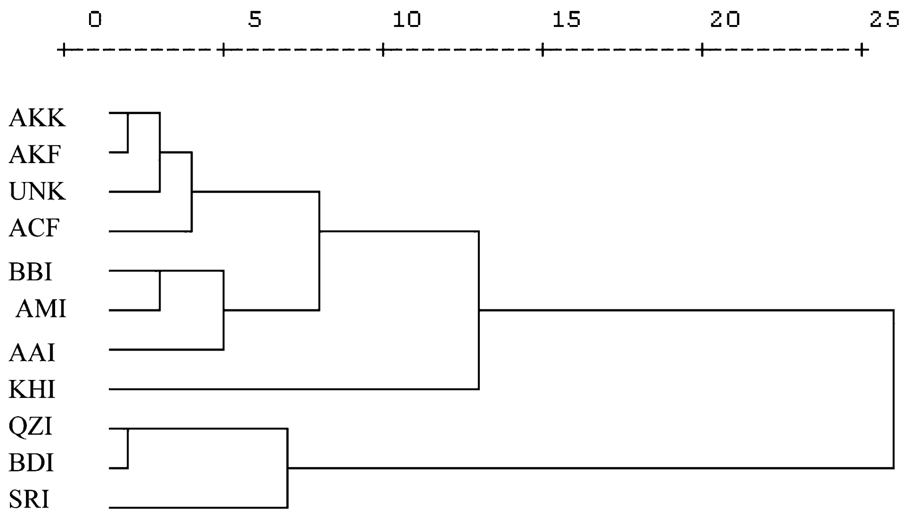

Fig. 1 Dendrogram representing morphological relationships among *Pistacia* genotype using ward method. AKK: *P. atlantica* subsp. *kurdica*, Kerman. UNK: Unknown, Kerman. AKF: *P. atlantica* subsp. *kurdica*, Fars. BBI: Garden mastic, Institute ACF: *P. atlantica* subsp. *cabulica*, Fars. KHI: *P. khinjuk*, Institute. AAI: *P. atlantica* subsp. *atlantica*, Institute. QZI: *P. vera* cv. Qazvini, Institute. BDI: *P. vera* cv. Badami Riz, Institute. SRI: *P. vera* var. Sarakhs, Institute. AMI: *P. atlantica* subsp. *mutica*, Institute

unknown genotype whereas it was present in the other genotypes. In a similar study, Zohary (1952) reported the absence of the leaf rachis wing in *P. vera*, *P. terebinthus* and *P. khinjuk*, but found it to be present in *P. atlantica* and *P. lentiscus*. The shape of the petiole cross-section was found to be round or flat with the exception of the unknown sample in that it was semi-round. In previous studies Zohary (1952); Yaltrik (1967) and Kafkas et al. (2002b) reported that the shape of the leaf petiole cross- section was round and angled in *P. terebinthus* and *P. eurycarpa* respectively.

Factor analysis showed that the characteristics of the leaves and nuts provide the main factor confirming 40% of the total variance, which must be taken into consideration when distinguishing pistachio rootstocks. According to Talhouk et al. (2000), nut characteristics in *Amygdalus communis* had the highest loading values for the first component in component analysis.

Cluster analysis could be used easily divide accessions with regards to species *P. vera*, *P. khinjuk* and *P. atlantica*. The *P. atlantica* along with *P. atlantica* subsp. *mutica* were located in a similar group and *P. atlantica* subsp. *kurdica*, *P. atlantica* Desf. subsp. *cabulica* (Stocks.) Rech. f. and the unknown genotype separated from them, therefore *P. atlantica* subsp. *kurdica* could be considered as being a distant species from *P. atlantica*. Yaltirik (1967) described and introduced *P. eurycarpa* as a new species. Zohary (1952) treated this accession as a subspecies of *P. atlantica* (subsp. *kurdica*), but it differs from the latter in at least two characteristics, having light green leaves on both sides and depressed fruit. Furthermore, its leaves are usually thicker and not numerous or neither does it have narrow leaflets as in *P. atlantica.* He also reported that *P. eurycarpa* is intermediate in terms of leaf characteristics between section Eu-Terebinthus and section Butmela. According to Yaltirik (1967), *P. eurycarpa* is a widespread species and often dominant in Iran, North of Iraq, Afghanistan and Southeastern Turkey. In this study it was found that *P. atlantica* and *P. atlantica* subsp. *mutica* formed the closest pairs genotypes. Zohary (1952) came to no conclusion as to whether *P. mutica* was a separate species or a subspecies of *P. atlantica*. The ovate leaflets and their reduced number were the only characteristics in which *mutica* differs from *P. atlantica*. Al Yafi (1978) described *P. mutica* based on leaf characteristics using herbarium samples and retained it within *P. atlantica*; also hybrid accessions located between *P. atlantica* subsp. *kurdica* and *P. atlantica* subsp. *mutica* (Table 7).

According to previous studies (Parfitt and Badenes 1997), *P. vera* and *P. khinjuk* were the two closest

Table 7 Classification subspecies of *P. atlantica* Desf. according to different researchers

Researcher name	Species	Subspecies
Zohary (1952)	*P. atlantica* Desf.	subsp. *latifolia* DC. (syn. *P. mutica* Fisch. et C. A. Mey., *P. cabulica* Stocks.)
		subsp. *kurdica*
Rechinger (1963)	*P. atlantica*	subsp. *mutica* (Fisch. et C. A. Mey.)
		subsp. *cabulica* (Stocks.)
		subsp. *kurdica* (Zoh.)
Yaltirik (1967)	*P. atlantica*	
	P. eurycarpa Yalt. (syn. subsp. *kurdica*)	
Zohary (1972)	*P. atlantica*	subsp. *atlantica*
		subsp. *cabulica*
		subsp. *mutica*
Al Yafi (1978)	*P. atlantica*	subsp. *latifolia* (syn. subsp. *mutica*)
		subsp. *cabulica*
		subsp. *kurdica*
Kafkas et al (2002b)	*P. atlantica*	
	P. eurycarpa (syn. subsp. *kurdica*)	
Karimi (2008)	*P. atlantica*	subsp. *mutica*
	P. eurycarpa (syn. subsp. *kurdica*)	

species while in the study undertaken *P. khinjuk* was closer to the *P. atlantica* species it can therefore be concluded that the present finding confirm the Kafkas et al. (2002b) report. According to Zohary (1972), *P. atlantica* subsp. *kurdica* with larger fruits, ovate and few paired leaflets closely resembled *P. vera.* He also reported that *P. atlantica* and *P. atlantica* subsp. *latifolia* (*P. atlantica* subsp. *mutica* and *cabulica*) are merely derivatives of *P. atlantica* subsp. *kurdica*, showing a trend towards increasing the number of leaflets per leaf and decreasing in nut dimensions.

Vegetative morphological characteristics of *P. khinjuk*, especially the leaves are very similar to *P. vera*. However, it has the smallest nuts between the species examined in the undertaken study and more resembles *P. atlantica*. According to Zohary (1952), fewer leaflets relate to a more ancestral species, therefore it can be concluded that *P. vera* is the most ancestral species followed by *P. khinjuk* and *P. atlantica*.

Using molecular characterization of the studied genotypes would allow for more obvious and clear distinguishing showing the genetic distances and the relationships of the accessions.

References

Al Yafı J (1978) New characteristics differentiating *Pistacia atlantica* subspecies. Candollea 33:201–208

Banihashemi Z (1995) The presence of pistachio gummosis in Iran. Paper presented at the 1st national workshop on the pistachio nut, Rafsanjan, Iran, 24–26 September 1995

Behboodi B (2003) Ecological distribution study of wild pistachios for selection of rootstock. Options Mediterraneennes, Serie A Numero 63:61–67

Engler A (1881) Burseraceae et Anacardiaceae. In: De Candolle AC (ed) Monographie Phanerogamarum, vol 4. Paris, pp 284–293

Farivar-Mehin H (1995) Study of the root-knot nematodes (*Meliodogyne* spp.) on pistachio in Kerman province. Paper presented at the 1st national workshop on the pistachio nut, Rafsanjan, Iran, 24–26 September 1995

Grundwag M, Werker W (1976) Comparative wood anatomy as an aid to identification of *Pistacia* species. Israel J Bot 25:152–167

IPGRI (1998) Descriptors for *Pistacia* spp. (excluding *P. vera* L.). International Plant Genetic Resources Institute, Rome, Italy

Kafkas S, Perl-Treves R (2001) Morphological and molecular phylogeny of *Pistacia* species in Turkey. Theor Appl Genet 102:908–915. doi:10.1007/s001220000526

Kafkas S, Cetine MS, Perl-Treves R (2002a) Molecular variation between and within *Pistacia* species in Turkey. HortSci 37:168–171

Kafkas S, Ebru K, Perl-Treves R (2002b) Morphological diversity and germplasm survey of three wild *Pistacia* species in Turkey. Genet Resour Crop Evol 49:261–270. doi:10.1023/A:1015563412096

Parfitt D, Badenes ML (1997) Phylogeny of the genus *Pistacia* as determined from analysis of the chloroplast genome. Proc Natl Acad Sci USA 94:7987–7992. doi:10.1073/pnas.94.15.7987

Rechinger KH (1963) Anacardiaceae. In: Rechinger KH (ed) Flora Iranica, vol 63. pp 1–9

Talhouk SN, Lubani RT, Baaldaki R et al (2000) Phenotypic diversity and morphological characterization of *Amygdalus* L. species in Lebanon. Genet Resour Crop Evol 47:93–104. doi:10.1023/A:1008763021129

Yaltirik F (1967) Anacardiaceae. In: Davis PH (ed) Flora of Turkey, vol 2. pp 544–591

Zohary M (1952) A monographical study of the genus *Pistacia*. Palestine J Bot 5:187–228

Zohary M (1972) *Pistacia* L. Flora Palestine. Isr Acad Sci Humanit Jerus 2:187–228