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Morphological Evaluation of Iranian Mulberry Genotypes in Kerman Province, Iran

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ABSTRACT

Mulberry (*Morus* spp.) is an economically important plant, and Iran is among the most important mulberry producer countries. Meager information is available on the number of mulberry species and the characteristics of genotypes in Kerman Province. In this study, we used Principal Component Analysis (PCA) to categorize a number of important mulberry traits from different parts of Kerman. A total of fifteen white and black mulberry genotypes were selected from four regions located in different parts of Kerman Province, in 2021. Fourteen qualitative and 15 quantitative variables were measured. The highest and the lowest Coefficient of Variance (CV) was found for leaf shape and fruit length, respectively. The strongest positive correlation was obtained between the number of second-degree shoots and number of shoots. PCA showed that the first five and six components among qualitative and quantitative variables explained 87.82 and 90.87% of the total variation, respectively. The dendrogram biplot classified genotypes into five groups based on quantitative and into four distinct groups in accordance to qualitative variables. The grouping of genotypes did not follow their geographical origin. This study revealed high morphological diversity in the mulberry genotypes dispersed in Kerman, supporting their potential uses for mulberry breeding programs.

Keywords: *Morus* spp., Native mulberry, Principal Component Analysis, White and black mulberry.

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INTRODUCTION

Mulberry (*Morus* spp.) of family Moraceae is an economically important plant being used for sericulture, fruit consumption, wood, landscape design, and medicinal purposes (Imran *et al.,* 2010; Rohela *et al.,* 2020). It can be cultivated in different habitats i.e. mountains, plains and valleys in varied plant growth habits viz., bushes, shrubs and trees (Yuan and Zhao, 2017). Iran is one of the most important mulberry producer countries with more than 18,000 metric-tons production in the world (Ahmadi *et al.,* 2020). The existence of two species of this genus including white (*Morus alba* L.) and black (*Morus nigra* L.) mulberries have been reported in some parts of Iran (Azizian *et al.,* 2000). The study of morphological traits on mulberry genotypes from 10 provinces of the country showed that leaf margin, petiole length, and inflorescence diameter had a higher variation than the rest variables. A positively significant correlation between harvest time and inflorescence shape was observed (Fakhraei Lahiji *et al.,* 2016). Other studies on Iranian mulberry population revealed that the Ghorgan and Shahrood populations had the highest coefficient of variations for morphological, physiological, and biochemical traits. Both fruit size and fruit taste were positively correlated with foliage–related traits (Ebrahimi *et al.,* 2021).

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However, there exists a poor understanding of the diversity of mulberry genotypes of Kerman Province. Mulberry genotypes have become mainly naturalized in disturbed areas such as roadsides and the edges of tree lots, along with urban areas in Kerman. However, global warming and drought stress are two most limiting factors for mulberry productivity (Jhansilakshmi *et al.,* 2014). Nevertheless, good yield of native mulberries grown in sub-tropical climate of Kerman Province exhibits relatively higher resistance to high temperature during the growing seasons. This fact enables their potential exploitation in breeding programs. Despite such a wide diversity, less information is available on the number of species and the characteristics of genotypes available in this province. Therefore, understanding the diversity among various mulberry genotypes is necessary for selection of more parental lines for improving agronomic traits of the existing varieties and identification of superior genotypes, which is a fundamental step in breeding program. Various types of data are used to analyze the genetic diversity in the collections, of which morphological and horticultural traits are more common for the distinction of the accessions (Höfer *et al.,* 2012). Multivariate analysis is used to address the situations where multiple measurements are made on each trait and to measure the relations between them (Olkin and Sampson, 2001). Principle Component Analysis (PCA) as a type of multivariate analysis creates a new set of orthogonal variables that contains the same information as the original set. It rotates the axes of variation to give a new set of orthogonal axes, ordered so that they summarize decreasing proportions of the variation. Associations between traits emphasized by this method may correspond to genetic linkage (Iezzoni and Pritts, 1991). PCA is a useful approach within this context (Mohammadi and Prasanna, 2003) and was previously used in morphological studies of some mulberry species in Iran (FakhraeiLahiji *et al.,* 2016; Ebrahimi *et al.,* 2021).

In this study, we used this statistical method to categorize the number of important mulberry traits from different parts of the province. The aim of this study was to investigate and document the phenotypic diversity of native mulberry genetic resources in Kerman Province using quantitative and qualitative morphological traits.

MATERIALS AND METHODS

A total of fifteen samples of mulberry genotypes was collected from four regions located in different parts of Kerman Province, Iran, in 2021 (Table 1). Samples of leaves were picked during the summer. The fruits were harvested at horticultural maturity of respective genotypes (started from the early June to mid-August). Samples were collected according to Ebrahimi *et al.* (2021). The morphological traits were determined as per the IPGRI mulberry descriptor (IPGRI, 2000). In total, 29 morphological traits, including 14 qualitative, and 15 quantitative variables, were characterized. Fourteen qualitative traits included tree vigor, tree growth habit, shoot color, phyllotaxy, leaf shape, leaf thickness, leaf base, lobe depth, leaf margin, leaf texture, leaf lamina, leaf color, leaf hairiness, and stipule. These variables were determined and classified visually. Further, 15 quantitative traits such as leaf dry weight, fruit dry weight, fresh fruit weight, leaf fresh weight, fruit width, fruit length, inflorescence width, inflorescence length, number of female flower clusters, petiole length, leaf width, leaf length, internode length, number of second-degree shoots, and number of shoots were also examined (Table 2). Number of female flower clusters, and second-degree shoots were determined by counting. All measurable data on inflorescences, internodes and leaves were evaluated by ruler and caliper. The weights of fresh and dry fruits and leaves were determined by precision scales. For qualitative and quantitative traits, non-parametric and parametric statistical methods were used, respectively, so, for each of these traits, descriptive statistics, correlation matrix and PCA presented were calculated separately (Tables 3, 4, 5, 6, and 7). Both qualitative and quantitative variables were

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Table 1. Origin and location of 15 studied mulberry genotypes in Kerman Province.

Collector no [a]	Type	Elevation above the sea (m)	Latitude (N)	Longitude (E)	Sampling location	Region
JF/AM/1	White mulberry	2239	"46 ' 42˚ 30	57˚ 27' 35"	Feyzabad	Ravar
JF/AM/2	White mulberry	2169	"36 ' 20˚ 31	56˚ 28' 59"	Feyzabad	Ravar
JF/AM/3	White mulberry	2166	"35 ' 20˚ 31	56˚ 29' 18"	Feyzabad	Ravar
JF/AM/4	Black mulberry	2163	"38 ' 20˚ 31	56˚ 29' 54"	Feyzabad	Ravar
JF/AM/5	Black mulberry	1761	"05 ' 16˚ 30	57˚ 01' 17"	In Kerman City (Agriculture Station)	Kerman
JF/AM/6	White mulberry	1762	"05 ' 16˚ 30	57˚ 01' 16"	In Kerman City (Agriculture Station)	Kerman
JF/AM/7	Black mulberry	1830	"27 ' 07˚ 30	57˚ 03' 37"	Ghanateghestan	Joopar
JF/AM/8	White mulberry	1852	"30 ' 04˚ 30	57˚ 13' 55"	Ghanateghestan	Joopar
JF/AM/9	Black mulberry	1836	"34 ' 07˚ 30	57˚ 03' 30"	Ghanateghestan	Joopar
JF/AM/10	Black mulberry	2021	"66 ' 09˚ 33	45˚ 86' 23"	Bidkhoon	Bardsir
JF/AM/11	White mulberry	1752	"45 ' 19˚ 30	57˚ 03' 45"	Surrounding gardens	Kerman
JF/AM/12	White mulberry	1744	"23 ' 19˚ 30	56˚ 56' 02"	Surrounding gardens	Kerman
JF/AM/13	Black mulberry	1791	"16 ' 17˚ 30	57˚ 07' 39"	Surrounding gardens	Kerman
JF/AM/14	White mulberry	2023	"66 ' 09˚ 33	45˚ 86'24"	Bidkhoon	Bardsir
JF/AM/15	White mulberry	2027	"63 ' 09˚ 33	45˚ 86' 24"	Bidkhoon	Bardsir

[a] JF/AM/ ….: Implying Javad Farrokhi/Abbas MirJalili/ …. Serial number.

analyzed by SPSS (Inc., Chicago, IL, USA, Norusis, 1998).

RESULTS AND DISCUSSION

Descriptive statistics

The genotypes like white mulberry of Feyzabad (JF/AM/3), white mulberry of Kerman (JF/AM/6), black mulberry of Bidkhoon (JF/AM/10), and both white mulberries of Bidkhoon (JF/AM/14, 15) were found to be spreading in nature; however, black mulberry and white mulberries collected from the surroundings of Kerman Province (JF/AM 5, 11) were semi erect in their growth habit. The strongest tree vigor was found in the white mulberry of Feyzabad (JF/AM/3) followed by the black mulberry of Feyzabad (JF/AM/4), black mulberry of Ghanateghestan (JF/AM/7), white mulberry of Ghanateghestan (JF/AM/8), black mulberry of Bidkhoon (JF/AM/10), and both white mulberries of Bidkhoon (JF/AM/14, 15) (Tables 1, and 2). The highest (3.6 g) and the lowest (2.1 g) fruit fresh weight was obtained in white mulberry (JF/AM/11) and black mulberry (JF/AM/13), respectively (Tables 1, 2). Number of female flower clusters was between two and three, among 15 studied genotypes. The highest

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Table 2. Measured variables of the studied mulberry genotypes.*

Genotype (No)	S	LH	LC	LL	LTe	LM	LD	LB	LTh	LS	Ph	SC	TGH	TV	LDW	FDW	FFW	LFW	FW	FL	IW	IL	NFFC	PL	LW	LL	InL	NSDS	NS
1	3	5	7	3	3	5	3	7	3	3	7	7	3	5	0.06	0.55	3.0	3.2	1.5	3.4	3.5	5.5	3	5.9	8.6	12.8	3	13	6
2	3	3	7	3	3	3	3	5	5	3	7	7	3	5	0.05	0.63	2.5	4.2	2.1	3.2	3.3	4.4	2	5.8	9.1	6.13	2.5	15	7
3	3	3	7	3	3	3	5	5	3	3	7	3	7	7	0.05	0.54	2.4	2.9	1.8	3.2	3.5	4.5	2	6	8.8	13	3.3	16	7
4	3	5	3	3	3	7	5	7	5	1	7	3	3	7	0.07	0.67	2.5	4.1	2.1	3.4	4.1	6.5	3	5.5	10	12.4	3.3	17	9
5	3	5	7	3	5	5	7	3	7	9	5	5	5	5	0.06	0.59	2.6	3.3	1.3	3.5	2.8	5.5	2	4.7	10.5	14.1	3.2	12	5
6	7	5	3	3	7	5	3	5	3	3	5	7	7	3	0.07	0.72	2.5	3.3	1.6	4.1	3.5	6.1	2	6.9	8.2	12.3	2.2	13	6
7	7	3	3	7	7	5	7	3	3	1	5	7	3	7	0.06	0.75	2.2	2.9	2.3	3.2	2.5	4.8	2	6.7	11.2	14.5	4.4	17	8
8	3	5	7	5	7	5	5	3	5	5	5	5	3	7	0.08	0.57	2.5	2.8	1.7	3.9	3.2	4.5	3	5.8	8.4	13.5	3	14	5
9	3	7	7	7	5	5	5	5	5	3	7	5	3	5	0.05	0.73	2.8	2.9	1.9	3.1	3.9	6.5	2	4.5	8.5	9.2	2.5	13	6
10	5	5	5	3	3	3	5	7	5	7	7	3	7	7	0.07	0.76	2.4	2.8	1.5	3.6	3.4	4.5	2	4.7	7.5	10.2	2.4	15	8
11	3	5	7	3	3	5	3	7	7	9	5	3	5	5	0.07	0.55	3.6	3.3	1.3	3.5	3.8	6.5	2	5.7	9.5	14.1	3.2	12	6
12	7	5	4	3	3	5	5	5	3	3	3	7	3	3	0.07	0.75	2.5	3.1	1.4	3.1	3.5	6.1	2	5.9	8.2	12.3	3.4	15	5
13	7	5	5	5	7	5	3	5	3	5	5	7	3	3	0.05	0.58	2.1	3.3	1.3	4.5	2.8	6.5	3	4.7	10.8	14.5	3.1	12	5
14	5	3	3	3	3	3	5	7	5	7	3	3	7	7	0.05	0.77	2.4	2.8	1.2	3.6	3.4	4.5	2	4.5	7.5	10.2	2.4	15	8
15	3	3	3	5	7	5	5	3	3	9	3	3	7	7	0.08	0.76	2.4	3.8	1.4	3.1	3.2	6.5	2	4.5	8.5	11.2	3.4	16	8

* Scale based on mulberry descriptor IPGRI, 2000. **Variables:** Stipule (S), Leaf Hairiness (LH), Leaf Color (LC), Leaf Lamina (LLa), Leaf Texture (LTe), Leaf Margin (LM), Lobe Depth (LD), Leaf Base (LB), Leaf Thickness (LTh), Leaf Shape (LS), Phyllotaxy (Ph), Shoot Color (SC), Tree Growth Habit (TGH), Tree Vigor (TV), Leaf Dry Weight (LDW), Fruit Dry Weight (FDW), Fresh Fruit Weight (FFW), Leaf Fresh Weight (LFW), Fruit Width (FW), Fruit Length (FL), Inflorescence Width (IW), Inflorescence length (IL), Number of female flower clusters (NFFC), Petiole Length (PL), Leaf Width (LW), Leaf Length (LL), Internode Length (IL), Number of Second-Degree Shoots (NSDS), Number of Shoots (NS). **Genotypes:** (1, 2 and 3) White mulberry of Feyzabad Ravar, (4) Black mulberry of Feyzabad Ravar, (5) Black mulberry of Kerman City, (6) White mulberry of Kerman City, (7) Black mulberry of Ghanateghestan, (8) White mulberry of Ghanateghestan, (9) Black mulberry of Ghanateghestan, (10) Black mulberry of Bidkhoon, (11 and 12) White mulberry of surrounding gardens of Kerman, (13): black mulberry of surrounding gardens of Kerman, (14 and 15) White mulberry of Bidkhoon.

Table 3. The descriptive analysis of 29 qualitative and quantitative variables.

Qualitative variables	Minimum	Maximum	Mean	Std deviation	CV%
Stipule	3.00	7.00	4.33	1.79	41.33
Leaf hairiness	3.00	7.00	4.46	1.18	26.45
Leaf color	3.00	7.00	5.2	1.85	35.57
Leaf lamina	3.00	7.00	3.93	1.48	37.65
Leaf texture	3.00	7.00	4.6	1.88	40.86
Leaf margin	3.00	7.00	4.6	1.12	24.34
Lobe depth	3.00	7.00	4.6	1.35	29.34
Leaf base	3.00	7.00	5.13	1.59	30.99
Leaf thickness	3.00	7.00	4.33	1.44	33.25
Leaf shape	1.00	9.00	4.73	2.81	59.40
Phyllotaxy	3.00	7.00	5.40	1.54	28.51
Shoot color	3.00	7.00	4.80	2.21	46.04
Tree growth habit	3.00	7.00	4.60	1.88	40.86
Tree vigor	3.00	7.00	5.53	1.59	28.75
Quantitative variables	Minimum	Maximum	Mean	Std. Deviation	CV%
Leaf dry weight	0.5	0.8	0.06	0.01	16.66
Fruit dry weight	0.57	0.77	0.67	0.09	13.63
Fresh fruit weight	2.1	3.6	2.56	0.35	13.67
Leaf fresh weight	2.8	4.2	3.24	0.45	13.88
Fruit width	1.2	2.3	1.63	0.33	20.24
Fruit length	1.20	2.3	3.49	0.40	11.46
Inflorescence width	2.5	4.10	3.36	0.42	12.50
Inflorescence length	4.4	6.5	5.52	0.90	16.30
Number of female flower clusters	2.00	3.00	2.26	0.45	19.91
Petiole length	4.5	6.9	5.45	0.80	14.67
Leaf width	7.5	11.2	9.02	1.14	12.63
Leaf length	6.13	14.50	12.02	2.31	19.21
Internode length	2.20	4.40	3.02	0.56	18.54
Number of second degree shoots	12.00	17.00	14.33	1.75	12.21
Number of shoots	5.00	9.00	6.60	1.35	20.45

Table 4. Correlation matrix of 14 qualitative variables using Spearman method in 15 mulberry genotypes.[a]

	S	LH	LC	LLa	LTe	LM	LD	LB	LTh	LS	Ph	SC	TGH	TV
S	1.00													
LH	-0.20	1.00												
LC	-0.75*	0.11	1.00											
LLa	0.23	0.20	-0.06	1.00										
LTe	0.56	0.11	-0.30	0.56	1.00									
LM	0.50	0.44	-0.44	0.20	0.30	1.00								
LD	0.08	-0.04	-0.11	0.44	0.29	0.19	1.00							
LB	-0.16	0.21	-0.14	-0.48	-0.74*	0.02	-0.55	1.00						
LTh	-0.48	0.36	0.33	-0.09	-0.10	0.10	0.37	-0.20	1.00					
LS	-0.20	0.25	0.44	-0.31	-0.01	-0.30	0.28	-0.21	0.67*	1.00				
Ph	-0.50	0.06	0.27	-0.25	-0.89**	-0.27	-0.40	0.79**	-0.06	-0.23	1.00			
SC	0.37	-0.16	-0.04	0.22	0.44	0.04	-0.32	-0.31	-0.32	-0.24	-0.39	1.00		
TGH	0.34	-0.11	-0.13	-0.48	-0.07	-0.48	-0.04	0.14	-0.15	0.38	-0.04	-0.36	1.00	
TV	-0.18	-0.30	-0.03	0.18	-0.20	-0.05	0.51	0.01	0.04	-0.07	0.18	-0.61	-0.13	1.00

number of second-degree shoots was observed in the black mulberry of Feyzabad (JF/AM/4), and black mulberry of Ghanateghestan (JF/AM/7), whereas the lowest number was in black mulberry of Kerman (JF/AM/5), white and black mulberries of surrounding gardens of Kerman (JF/AM/11, 13). Number of shoots

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Table 5. Correlation matrix of 15 quantitative variables using Pearson method in 15 mulberry genotypes.[a]

	LDW+	FDW	FFW	LFW	FW	FL	IW	IL	NNFC	PL	LW	LLe	IL	NSDS	NS
LDW	1.00														
FDW	-0.01	1.00													
FFW	0.03	-0.36	1.00												
LFW	-0.14	-0.08	0.06	1.00											
FW	-0.34	0.32	-0.44	0.32	1.00										
FL	0.77**	0.02	-0.06	-0.14	-0.50	1.00									
IW	0.02	0.01	0.43	0.30	0.03	-0.03	1.00								
IL	0.04	0.26	0.46	0.24	-0.01	0.04	0.56	1.00							
NNFC	0.67*	-0.43	0.39	0.16	-0.02	0.22	0.33	0.178	1.00						
PL	0.17	-0.04	-0.34	0.07	0.35	0.29	-0.26	-0.15	0.07	1.00					
LW	-0.23	-0.00	-0.31	0.26	0.43	-0.39	-0.50	0.09	-0.04	0.17	1.00				
LLe	0.44	-0.23	-0.16	-0.44	-0.22	0.29	-0.38	0.06	0.29	0.30	0.41	1.00			
InL	-0.05	-0.10	-0.40	-0.13	0.45	-0.39	-0.52	-0.17	0.13	0.29	0.81**	0.63*	1.00		
NSDS	-0.08	0.21	-0.67*	0.19	0.76*	-0.36	0.02	-0.27	0.06	0.31	0.33	0.03	0.54	1.00	
NS	-0.08	0.46	-0.47	0.32	0.60	-0.36	0.23	0.00	-0.01	0.10	0.20	-0.14	0.29	0.86**	1.00

[a] Leaf Dry Weight (LDW), Fruit Dry Weight (FDW), Fresh Fruit Weight (FFW), Leaf Fresh Weight (LFW), Fruit Width (FW), Fruit Length (FL), Inflorescence Width (IW), Inflorescence Length (IL), Number of Female Flower Clusters (NFFC), Petiole Length (PL), Leaf Width (LW), Leaf Length (LLe), Internode Length (IL), Number of Second Degree Shoots (NSDS), Number of Shoots (NS). * and **: Correlations significant at P< 0.05 and P< 0.01, respectively.

ranged from 9 in black mulberry of Feyzabad (JF/AM/4) and 5 in black mulberry of Kerman (JF/AM/5), white mulberry of Ghanateghestan (JF/AM/8), white mulberry (JF/AM/12) and black mulberry in surrounding gardens of Kerman (JF/AM/13) (Tables 1,3). In all 15 studied individuals, full-bloom of female flowers varied between 27th of April and 28th of May. The date of fruit maturity occurred from 16th June to18th July (data not presented). These times were very similar to the phenological data obtained on Turkish mulberries (Çöçen *et al.,* 2018). Coefficient of Variation (CV) was in the highest value for leaf shape (CV= 59.40%), and shoot color (CV= 46.04%). Minimum values of CV were observed in inflorescence width (CV= 12.50%), and fruit length (CV= 11.46%) (Table 3). The CV and mean are the most commonly used statistical indices (Ebrahimi *et al.,* 2021). In previous studies on mulberry genotypes, CVs ranged from 12.78 to 84.09 % (Krishna *et al.,* 2018), 0 to 203.19% (Farahani *et al.,* 2019), and 25.9 to 91.4 (Ebrahimi *et al.,* 2021). Fruit dry weight, fruit width and leaf length was reported 84.04 gr, 20.25 mm, and 25.55mm%, respectively by Ebrahimi *et al.* (2021). The main reason for the observed high CV in qualitative traits refers to type of sampling and its statistical analysis (Bakhshalizadeh *et al.,* 2012). Mean of dry fruit weight was (0.67 g), fresh fruit weight (2.56 g), and fruit length (3.49 cm) (Table 3). The highest mean of dry fruit weight (0.86 g), fresh fruit weight (3.75 g), and fruit length (2.12 cm) were reported in Kermanshah genotypes by Fakhraei *et al.* (2016). Our results showed that Kerman genotypes have enough marketability in terms of dry weight and fruit length to introduce to the markets. In mulberry production, analyzing the coefficients of correlation between different traits involved provides informative data about the relative effect of every character on yield.

Relationships between Variables

In this study, Pearson's and Spearman's coefficients were used for quantitative and qualitative traits, respectively. Significant correlations were found between some of the variables. The highest positive correlations were shown between number of second-degree shoots and number of shoots (r= 0.86, P< 0.05), followed by leaf width and

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Table 6. Eigenvalues, proportion of total variability as well as eigenvector and correlation between 14 qualitative variables and the first five Principal Components (PCs) in 15 mulberry genotypes.

Item	PC axis				
Eigenvalue	3.86	2.78	2.11	1.94	1.57
Proportion	27.63	19.87	15.12	13.91	11.27
Cumulative	27.63	47.50	62.63	76.55	87.82
			Eigenvector		
Variable[a]	PC1	PC2	PC3	PC4	PC5
S	0.66	-0.47	-0.35	-0.23	0.24
LH	-0.05	0.29	0.34	0.47	0.60
LC	-0.45	0.48	-0.06	0.41	-0.54
LLa	0.61	0.18	0.46	-0.11	-0.24
LTe	0.93	0.11	-0.09	0.12	0.06
LM	0.36	0.05	0.65	0.09	0.52
LD	0.38	0.67	0.03	-0.53	0.05
LB	-0.71	-0.49	0.21	-0.02	0.37
LTh	-0.19	0.82	0.02	0.20	0.20
LS	-0.18	0.70	-0.57	0.21	0.18
Ph	-0.85	-0.25	0.32	-0.08	-0.09
SC	0.53	-0.38	-0.02	0.57	-0.36
TGH	-0.19	-0.13	-0.82	-0.22	0.35
TV	-0.15	0.29	0.25	-0.83	-0.18

[a] Stipule (S), Leaf Hairiness (LH), Leaf Color (LC), Leaf Lamina (LLa), Leaf Texture (LTe), Leaf Margin (LM), Lobe Depth (LD), Leaf Base (LB), Leaf Thickness (LTh), Leaf Shape (LS), Phyllotaxy (Ph), Shoot Color (SC), Tree Growth Habit (TGH), Tree Vigor (TV).

Table 7. Eigenvalues, proportion of total variability as well as eigenvector and correlation between 15 quantitative variables and the first six Principal Components (PCs) in 15 mulberry genotypes (for abbreviation see below).

Item	PC axis					
Eigenvalue	4.27	2.97	2.18	1.87	1.29	1.03
Proportion	28.49	19.81	14.55	12.46	8.62	6.90
Cumulative	28.49	48.31	62.87	75.34	83.96	90.87
			Eigenvector			
Variable[a]	PC1	PC2	PC3	PC4	PC5	PC6
LDW	-0.34	0.55	0.59	-0.35	0.03	-0.10
FDW	0.28	-0.32	-0.05	-0.58	0.63	0.00
FFW	-0.71	-0.23	0.15	0.53	0.03	-0.03
LFW	0.17	-0.47	0.42	0.20	-0.23	0.56
FW	0.81	-0.30	0.22	0.00	-0.05	0.09
FL	-0.51	0.48	0.25	-0.56	0.05	0.29
IW	-0.34	-0.64	0.55	-0.01	0.00	-0.19
IL	-0.25	-0.31	0.44	0.25	0.70	0.18
NFFC	-0.23	0.26	0.81	0.26	-0.23	-0.20
PL	0.35	0.41	0.24	-0.24	-0.19	0.51
LW	0.67	0.26	0.00	0.51	0.28	0.26
LLe	0.09	0.85	0.17	0.18	0.32	-0.13
InL	0.73	0.50	0.05	0.39	0.11	-0.16
NSDS	0.85	-0.08	0.32	-0.19	-0.19	-0.24
NS	0.69	-0.36	0.38	-0.26	0.04	-0.24

[a] Leaf Dry Weight (LDW), Fruit Dry Weight (FDW), Fresh Fruit Weight (FFW), Leaf Fresh Weight (LFW), Fruit Width (FW), Fruit Length (FL), Inflorescence Width (IW), Inflorescence Length (IL), Number of Female Flower Clusters (NFFC), Petiole Length (PL), Leaf Width (LW), Leaf Length (LL), Internode Length (IL), Number of Second Degree Shoots (NSDS), Number of Shoots (NS).

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internode length (r= 0.81, P< 0.05), phyllotaxy and leaf base (r= 0.79, P< 0.05), leaf dry weight and fruit length (r= 0.77, P< 0.05), leaf thickness and leaf shape (r= 0.67, P< 0.05). The highest negative correlation was found between leaf texture and phyllotaxy (r= -0.89, P< 0.01), stipule and leaf color (r= -0.75, P< 0.05), leaf texture and leaf base (r= -0.74, P< 0.05), and fresh fruit weight and number of second-degree shoots (r= -0.67, P< 0.05) (Tables 4, and 5). Tree growth habit was negatively correlated with tree vigor. This result is in line with the ones reported in previous studies of Iranian mulberries (Ebrahimi *et al.*, 2021). Results of this study confirm high and close correlation between foliar and floral variables and leaf dry weight and number of female flower cluster and fruit length. Correlation coefficients between the phenological traits could determine whether selection for one trait may affect the other traits. Response to direct selection for these variables may be unpredictable, unless there is a good control of environmental variables.

Principal Component Analysis (PCA)

PCA, as a flexible approach by reduction of numerous correlated variables to few main factors, could be successfully utilized to comprehend the patterned variation in a set of variables. In view of the diversity of mulberry accessions under study, the analysis into main components was carried out to determine the contribution and effect rate of each trait under study on the present diversity. As a criterion to extract the main principal components, eigenvalues greater than one were taken into account. The first five components among qualitative variables ($\lambda1= 3.86$, $\lambda2= 2.78$, $\lambda3= 2.11$, $\lambda4= 1.94$, $\lambda5= 1.57$) and the first six components of quantitative variables ($\lambda1= 4.27$, $\lambda2= 2.97$, $\lambda3 = 2.18$, $\lambda4= 1.87$, $\lambda5= 1.29$, $\lambda6= 1.03$,) explained 87.82 and 90.87% of the total variation, respectively (Tables 6, 7). The type of measurement of both quantitative and qualitative traits can also affect the number of specific vectors and variances corresponding to them (Abdi and Williams, 2010). In qualitative variables, PC1 explaining 27.63% of the total variation, was positively associated with stipule, leaf lamina, leaf texture, leaf margin, and lobe depth. Variables that positively loaded on PC2, explaining 19.87% of the total variation, were leaf hairiness, leaf color, leaf lamina, leaf texture, lobe depth, leaf thickness, and leaf shape (Table 6). Among quantitative variables, leaf fresh weight, fruit width, leaf width, inflorescence length, number of second-degree shoots, number of shoots, and phyllotaxy were found influential in the first Component (PC1), thereby, explaining 28.49% of the total variation. Variables that positively loaded on PC2 explained 19.81% of the total variation and included leaf dry weight, number of female flower clusters, phyllotaxy, leaf width, and leaf length. Both PC1 and PC2 were involved in foliar-related traits (Table 7). Merging PC1 and PC2 observations showed leaf lamina, leaf texture, lobe depth, leaf and dry weight, and phyllotaxy were substantial in classifying and summarizing the traits in the studied mulberries. These variables, as a part of leaf-related traits, are of great importance in the context of sericulture industry too. In a previous study conducted by Ebrahimi *et al*. (2021) on Iranian mulberries, the percentage of variability revealed that the first three components accounted for 40.62% of the whole variation. The PC1 contributed 19.76 % of the total variance and was mainly explained by blade length, blade width, length of main vein, diameter of petiole, fresh fruit weight, fruit dry weight, fresh fruit weight/ dry weight, fresh leaf weight, number of margins, petiole length, leaf base, and fruit diameter. The PC2 accounted for 12.35 % of the total variation and was mainly explained by total chlorophyll, chlorophyll a/b and carotenoid contents (Ebrahimi *et al.*, 2021). In another study on Iranian mulberry genotypes originated from 13 different regions of Iran, PC1 and PC2 revealed 32 and 23% of total variations,

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respectively (Fakhraei Lahiji *et al.,* 2016). Suresh *et al.* (2018) reported two first principal components obtained from original data accounted for 78.73% of total variation. Among all principal components, PC1 contributed the maximum (45.36%) to the total variation. Accordingly, the major contributing traits for diversity in the first principal component were foliage yield and primary branches per plant. Presence of positive and negative correlation trends between the components and the variables are interpreted by positive and negative loading. Similarly, for the second Principal Component (PC2), inter-nodal distance was the major contributor for the diversity. According to a dendrogram generated by PC1 and PC2, all 15 mulberry genotypes were classified into five and four separate groups on the basis of qualitative and quantitative variables, respectively. Based on qualitative variables, the first, second, third, fourth, and fifth groups included 2, 4, 4, 2, and 3 individuals, respectively (Figure 1). Among all genotypes, white mulberry (FA/SM/12), and two black mulberries (FA/SM/13, FA/SM/7) were loaded PC1 positively. They were mainly sampled in an area at 1,744 to 1,830 m above the sea (Table 1). In the four groups created based on quantitative traits, 5, 2, 4, and 4 genotypes existed in order. Five white mulberries comprising FA/SM/2, FA/SM/11, FA/SM/12, FA/SM/14, and FA/SM/15 were loaded PC1 positively (Figure 2). They were sampled at 1,744 to 2,169 m above the sea (Table 1). Genotypes FA/SM/12 from surrounding gardens of Kerman had high variability for stipule, leaf lamina, leaf texture, leaf margin, lobe depth, leaf fresh weight, fruit width, leaf width, inflorescence length, number of second-degree shoots, number of shoots, and phyllotaxy. This genotype could potentially be utilized in future mulberry breeding programs. Investigation of the created dendrograms based on both sets of traits divided them into separate groups. No distinctive segregation based on the geographical origin of genotypes was observed in biplot dendrograms based on qualitative and quantitative traits. This lack

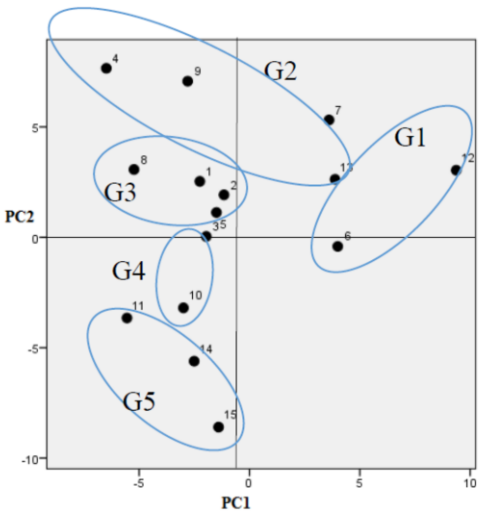

Figure 1. Biplot between PC1 and PC2 showing distribution of mulberry accessions based on qualitative variables. (**1, 2** and **3:** White mulberry of Feyzabad Ravar, **4:** Black mulberry of Feyzabad Ravar, **5:** Black mulberry of Kerman City, **6:** White mulberry of Kerman City, **7:** Black mulberry of Ghanateghestan, **8:** White mulberry of Ghanateghestan, **9:** black mulberry of Ghanateghestan, **10:** black mulberry of Bidkhoon, **11** and **12:** White mulberry of surrounding gardens of Kerman, **13:** Black mulberry of surrounding gardens of Kerman, **14** and **15**: White mulberry of Bidkhoon). G" stands for Group (G1: Group 1, G2: Group 2, G3: Group 3, G4: Group 4, G5: Group 5).

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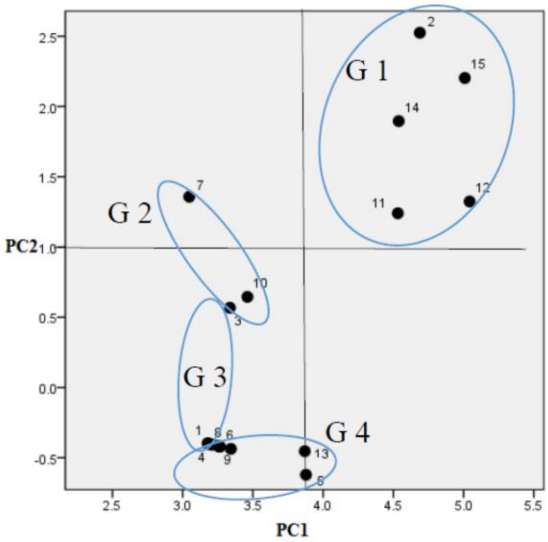

Figure 2. Biplot between PC1 and PC2 showing distribution of mulberry accessions based on quantitative variables. Symbols are defined under Figure 1.

of segregation is consistent with previous findings based on the morphological characteristics of mulberries (Fukuda *et al.*, 2011; Fakhraei Lahiji *et al.*, 2016).The results of biplots between PC1 and PC2 showed that the genotypes with a positive coefficient with both PCs were at a higher level in terms of traits related to both components. According to dendrogram based on qualitative traits, white mulberry of the surrounding gardens of Kerman (JF/AM/12), black mulberry of Ghanateghestan (JF/AM/7), black mulberry of Feyzabad Ravar(JF/AM/4), black mulberry of surrounding gardens of Kerman (JF/AM/13), black mulberry of Ghanateghestan (JF/AM/9), three white mulberries of Feyzabad Ravar (JF/AM/1, 2, 3), and white mulberry of Ghanateghestan were positively correlated with PC1 and PC2 (Figure 1). These genotypes had higher stipule, leaf margin, lobe depth, leaf hairiness, leaf color, leaf lamina, lobe depth, leaf thickness, and leaf shape. According to the dendrogram based on quantitative traits, white mulberry of Feyzabad Ravar (JF/AM/2), white mulberry of Bidkhoon (JF/AM/15), white mulberry of Bidkhoon (JF/AM/14), white mulberry of surrounding gardens of Kerman (JF/AM/11), white mulberry of surrounding gardens of Kerman (JF/AM/12), from the first group and black mulberry of Ghanateghestan (JF/AM/7) had positive coefficients in both PC1 and PC2 (Figure 2). They had higher leaf fresh weight, fruit width, leaf width, inflorescence length, number of second degree shoots, number of shoots, leaf dry weight, phyllotaxy, leaf width, leaf length, and number of female flower clusters than the other genotypes. Lower inter-cluster distance indicates close relationship and similarity among genotypes; therefore, such genotypes should not be used in hybridization programs as parents (Srivastava *et al.*, 2010).

CONCLUSIONS

Our study helped us to explain the morphological diversity among mulberry genotypes and identify the promising genotypes in Kerman Province, supporting the presence of a high level of genetic diversity. In this study, the clustering pattern of genotypes was independent of their geographical distances. Moreover, in terms of dry weight and fruit length, our results showed that Kerman genotypes have enough

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marketability to introduce to the markets. Generally, leaf characteristics showed greater superiority than the other traits. Existence of superior leaf traits and subsequent breeding programs on them can pave the way for the use of in genotypes in the sericulture industry in the future. Due to its good variables such as large leaf size, texture and weight, deeper lobes, high number of second-degree shoots, and number of shoots, FA/SM/12 is suggested for future researchers who will conduct studies on mulberry breeding and selection.

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ارزیابی مورفولوژیکی ژنوتیپ های توت ایرانی در استان کرمان، ایران

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چکیده

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توت (*Morus* spp.) گیاه مهم اقتصادی است و ایران از مهم ترین کشورهای تولید کننده آن می باشد. اطلاعات اندکی از تعداد گونه¬های توت و خصوصیات ژنوتیپ های استان کرمان در دسترس است. در این مطالعه از روش تجزیه به مولفه اصلی (PCA) برای دسته‌بندی تعدادی از صفات مهم توت از مناطق مختلف کرمان استفاده شد. در مجموع ۱۵ ژنوتیپ توت سفید و سیاه از چهار منطقه واقع در نقاط مختلف استان کرمان در سال ۱٤۰۰ انتخاب شدند. چهارده متغیر کیفی و ۱۵ متغیر کمی اندازه‌گیری گردید. بیشترین و کمترین ضریب تغییرات (CV) به ترتیب برای شکل برگ و طول میوه به دست آمد. قوی ترین همبستگی مثبت بین تعداد شاخه درجه دو و تعداد شاخساره به دست آمدتجزیه به مولفه اصلی نشان داد که پنج مولفه اول از بین صفات کمی و شش مؤلفه اول از بین صفات کیفی به ترتیب در برگیرنده ۸۷/۸۲ % و ۹۰/۸۷ %از کل تغییرات بودند. یه وسیله دندروگرام بای پلات ژنوتیپ ها بر اساس صفات کمی به پنج گروه و بر اساس متغیرهای کیفی به چهار گروه مجزا طبقه بندی گردیدند. گروه بندی ژنوتیپ ها مستقل از منشاء جغرافیایی آنها بود. این مطالعه تنوع مورفولوژیکی بالایی را در ژنوتیپ‌های توت پراکنده در کرمان نشان داد که موید کاربردهای بالقوه آنها برای برنامه‌های پرورش توت می باشد.

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