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Characterization of grapevine (*Vitis vinifera* L.) genotypes in Ilam province based on morphological traits

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A B S T R A C T

Purpose: Morphological screening of native grapevine genotypes is the fundamental step in vine breeding programs. In this study, selected morphological traits were to identify key traits and classify genotypes based on their morphological diversity. **Research method:** 22 grapevine cultivars and local genotypes from different vineyards in Ilam province were evaluated. A total of 33 morphological traits related to leaves and bunches were recorded based on the International Organization of Vine and Wine (OIV) grape descriptor. **Findings:** The results revealed high coefficients of variation for traits such as skin color (88.58%), pedicel length (58.99%), pedicel weight (58.99%), rachis weight (57.71%), berry weight (56.16%), indicating substantial morphological diversity among grapevine plants. The highest yield per vine was observed in the genotype “*GD3Chamanar*” with 65 kg per vine. Significant positive and negative correlations were found among some traits. Principal component analysis extracted ten components that together explained 87.18% of the total variance. The first principal component (PC1) was mainly associated with, leaf width and length, bunch weight and width, sugar content, dried fruit weight of bunch, rachis weight and dried fruit weight of peduncle, and berry separating from the pedicel. Cluster analysis grouped the cultivars and genotypes into four major clusters at an approximate Euclidean distance of 5, based on traits such as leaf length and width, fruit ripening time, average yield, bunch and bunch shoulder weights, berry length and weight, berry shape, berry hardness, and juiciness of berry flesh. The cultivar “*Zarde Vargaché*” and the genotype “*GD3Chamanar*” exhibited the highest average yield and are recommended as productive and well-adapted candidates for the Ilam province. **Research limitations:** Sample collection was the key challenges in this study. **Originality/Value:** The genotypes “*GF3 Kolm*”, “*GF2 Kolm*”, and “*GF1 Kolm*” from Badreh region with sugar content of 23.12%, 22.83%, and 21.53% °Brix respectively, are proposed for both table grape production and raisin processing.

Keywords:

Cluster analysis, Correlation coefficient, Grapevine, Morphological traits, Yield

INTRODUCTION

Grapes (*Vitis vinifera* L.) are among the most valuable and widely cultivated fruit crops, and their cultivated area continues to expand worldwide due to their high nutritional value and diverse applications (Khan et al., 2020; Kupe et al., 2021). Numerous grape genotypes have been identified, classified, and evaluated across the world (Aradhya et al., 2003). Based on morphological diversity both within and among species, several descriptor lists, manuals, and ampelographic studies have been developed for their identification (Bodor et al., 2003). Among plant organs, leaves exert greatest influence on morphological traits, while young shoots, bunches, and berries also play an important role in genotype characterization (Antolin et al., 2021). Species and cultivars of *Vitis*, characterized by their leaf morphological traits and developed through various methods, have been described for the purposes of genotype identification and the evaluation of diversity in wild *Vitis* species (Bodor et al., 2003).

Iran is one of the most suitable countries for grape cultivation due to its climatic diversity and specific weather conditions (Nejatian, 2006; Erfani-Moghadam et al., 2008; Haddadinejad et al., 2013; Rasouli et al., 2014; Mirfatah et al., 2024; Kazemi et al., 2024). Grapes are the third most produced horticultural crop in Iran, according to the 2023 Annual Report of the Ministry of Jihad Agriculture. This crop holds a special position among the country's horticultural products. The selection of the appropriate cultivars with morphologically and pomologically important characteristics is one of the key factors in vineyard establishment (Malheiro et al., 2013). The *Vitis vinifera* cultivars are known for producing the high-quality fruit and are grown under different climatic conditions. In Iran, these cultivars are utilized in various forms, including table grape, raisin, and syrup production (Kazemi et al., 2024). Morphology is one of the most prominent and distinctive traits of plant organs and it are widely recognized as one of the key tools for plant biologists and breeders. Several plant-based morphological methods are used to distinguish closely related cultivars (Antolin et al., 2021).

Local grape cultivars differ in their morphological traits, such as bunch and berry sizes. Studying phenology, harvest timing, productivity, and quality indices of local grape varieties is vital for preserving the product diversity. Additionally, these factors play a crucial role in ensuring food security, nutrition, and economic stability for numerous individuals, especially smallholder farmers and agricultural communities in rural regions (Ates et al., 2011; Sabir et al., 2010; Eyduran et al., 2015). The diversity of local grapes can serve as a safeguard against reduced crop production and provide unique ingredients for locally traditional foods and targeted dietary needs. Additionally, these varied grape cultivars represent a valuable reservoir of regionally adapted genes for enhancing new grape genotypes. Given its role and potential in exports, this crop can be considered strategically important for development (Pallás, 2016; Sargolzaei et al., 2021). Moreover, numerous regions of the world are rich in valuable local grape varieties that have not yet been fully explored and identified (Eyduran et al., 2015). Research highlights the importance of preserving these varieties due to their genetic diversity and potential for adaptation to climate change. For example, studies have shown that local grape varieties often perform better physiologically under stress conditions compared to foreign and non-local varieties, demonstrating their resilience and adaptability (Florez-Sarasa et al., 2020). Because of global warming caused by climate change, grape cultivation may be severely affected in many regions of the world, which need to adapt to these changes, leading to altered planting dates and shorter phenological stages (Antoin et al., 2021).

One of the breeding programs aims to replace existing varieties with new ones that can perform better under expected environmental conditions. This solution could be one of the

most promising approaches in the future, although it represents a long-term strategy (Sargolzaei et al., 2021). In every grape-producing country, a wide range of local grape cultivars contributes to the global diversity of grapes (Gago et al., 2009; Antolin et al., 2021). Grapes from various cultivars exhibit considerable variation in berry morphology, especially regarding the size, shape, and color of the berries (Eyduran et al., 2015). Accurate identification of grape cultivars is crucial for grape growers because these economically significant crops are particularly vulnerable to the impacts of climate change, which affect both yield and quality (Sargolzaei et al., 2021).

In Iran, in several provinces, such as East and West Azerbaijan (Alizadeh, 2004), Qazvin (Nejatian, 2006; Haddadinejad et al., 2013), Sistan and Baluchestan (Hashemzahi et al., 2010), Hamedan (Rasouli et al., 2014), Markazi (Mirfatah et al., 2024), and Khuzestan (Kazemi et al., 2024), studies have been conducted on the collection of various local cultivars and genotypes to investigate morphological trait diversity. These studies have shown significant variation in some quantitative and qualitative traits of grape cultivars and genotypes.

Ilam province, with an area of 19,086 km², accounts for about 1.4% of the total area of the country (Rezazadeh Shafarudi, 2016). This province is one of the relatively forested regions of Iran. The northern region of the province has a mountainous climate, while the southern region features vast plains. Ilam province, with climatic diversity and suitable conditions for grapevine cultivation, has an area under cultivation of approximately 1,344 hectares, with an average yield of 6.5 tons per hectare, contributing to a total production of about 6,889 tons (Agricultural Statistics Yearbook, 2020). So far, no comprehensive research has been conducted on the diversity of local cultivars and genotypes in Ilam province. This lack of research has created a knowledge gap in grape breeding programs in Iran. Therefore, this study was conducted to: 1. Examine the morphological traits of grape varieties and genotypes in Ilam province; 2. Determine the morphological traits that have a substantial impact on yield; and 3. Apply these findings in grape breeding programs to benefit researchers and vine growers.

MATERIALS AND METHODS

Collection site of grape samples

In this study, leaf and fruit samples of grapes were collected from various locations across Ilam province (Table 1).

Table 1. Geographical locations of vineyards in Ilam province, located in western of Iran.

Region (Sampling site)	Longitude (UTM)	Latitude (UTM)	Altitude(m)	Precipitation(mm)
Chaviz Ilam	X=46.43	Y=33.52	1106	514
Vargach Lomar	X=46.83	Y=33.55	753	446
Chamanar Malekshahii	X=46.55	Y=33.25	961	527
Farkhinvand Sarable	X=47.022	Y=37.64	877	325
Kolm Badreh	X=46.92	Y=33.36	931	460

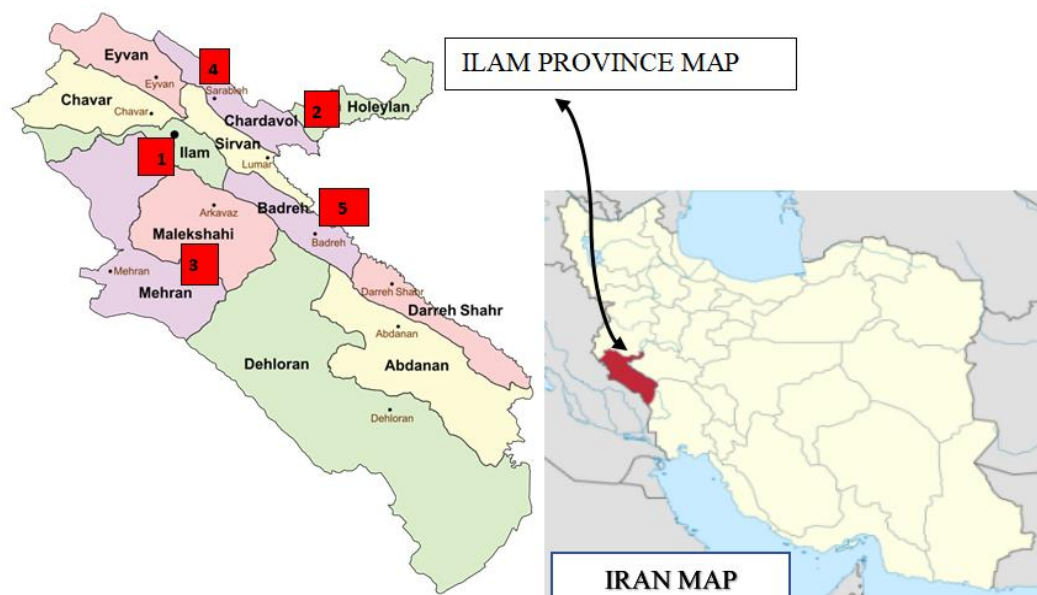


Fig. 1. Map of Ilam province located in western of Iran (sampling locations are marked in red).

Plant materials and measured traits

This research examines the morphological variation among 22 grape cultivars and genotypes from various regions of Ilam province, which exhibit significant climatic differences. The study aimed to investigate the botanical traits and variations in quantitative and qualitative characteristics based on morphological characteristics (Table 1). This study was conducted using 33 traits, including phenological, vegetative, leaf, berry and bunch related traits, according to the global descriptors for grape and related methods (OIV, 2007) (Table 2). Coding of some traits was performed following the grape descriptor (Bioversity International, 1983) (Table 3). The quantitative measurement of fruit sugar content was carried out using an analog handheld refractometer (Model MASTER-3M, ATAGO Co., Ltd., Japan). For the evaluation of the desired traits, three vines per genotype were selected, and leaves and bunches from these vines were assessed in five replicates. Quantitative traits, including bunch and berry weight, were assessed using a digital scale with a precision of 0.01 g. The length and diameter of berries were measured using a caliper (precision: 0.01 mm), and leaf length and width were measured with a ruler (precision: 0.01 mm) (Table 2).

Statistical analysis

Statistical analyses were performed using Microsoft Excel (Version 2016) and IBM SPSS Statistics software (Version 27.0). Frequency distributions of traits, descriptive statistics, simple correlation coefficients, cluster analysis, and principal component analysis (PCA) were conducted based on the number of cultivars and evaluated traits. The Pearson correlation coefficient was used to calculate simple correlations between traits. The coefficient of variation (CV %) was calculated by dividing the standard deviation of each trait by its mean. Principal component analysis (PCA) was performed using the varimax rotation method to maximize variance in the data. Principal components with eigenvalue equal to or greater than 0.50 were considered significant for identifying influential traits in each principal component. Cluster analysis and grouping of cultivars were conducted using Ward's method (minimum variance) with Euclidean distance, after standardizing the data (Rasouli et al., 2014).

Table 2. List of studied grape genotypes and cultivars in Ilam province.

Row	Variety and genotype name	Region	Row	Variety and genotype name	Region
1	Yaghooti Ilam	Chaviz Ilam	12	Yaghooti Vargache	Vargach Lomar Sirvan
2	Perlette	Chaviz Ilam	13	Yaghooti Farkhinevand	Farkhinvand Sarable
3	Asgari Ilam	Chaviz Ilam	14	Asgari Sefid Chamanar	Chamanar Malekshahi
4	Rasheh	Chaviz Ilam	15	GD Chamanar	Chamanar Malekshahi
5	Rasheh Vargache	Vargach Lomar Sirvan	16	GD1 Chamanar	Chamanar Malekshahi
6	Zarde Vargache	Vargach Lomar Sirvan	17	GD2 Chamanar	Chamanar Malekshahi
7	Bidaneh Sefid Vargache	Vargach Lomar Sirvan	18	GD3 Chamanar	Chamanar Malekshahi
8	Fakhrii Vargache	Vargach Lomar Sirvan	19	GD4 Chamanar	Chamanar Malekshahi
9	Asgari Sefid Vargache	Vargach Lomar Sirvan	20	GF1Kolm	Kolm Badreh
10	Shahani Sefid Vargache	Vargach Lomar Sirvan	21	GF2Kolm	Kolm Badreh
11	Sahebi Sefid Vargache	Vargach Lomar Sirvan	22	GF3Kolm	Kolm Badreh

G=genotype

Table 3. List of quantitative and qualitative traits and their measurement methods in grapevine genotypes and cultivars, based on the descriptors of OIV (2007), Bioversity International, and UPOV (2008).

Row	Trait	Abbreviation	Unit	Measurement method
1	Leaf width	Lwi	Cm	Digital caliper
2	Leaf length	LLe	Cm	Digital caliper
3	Leaf area	LA	mm ²	Leaf area measuring device
4	Fruit ripening time	FRT	Day	1= Very early, 3= Early, 5= Medium, 7= Late, 9= Very late
5	Bunch per vine	BuPerV	No.	Counting the number of bushes
6	Average yield	AYi	kg	Average bunch weight & number of bunches per plant
7	Bunch weight	BuWe	G	Digital scale
8	Bunch shoulder weight	BshWe	G	Digital scale
9	Ratio of bunch weight to bunch shoulder weight	BuWetoBshWe	G	Calculate the ratio of bunch weight to bunch shoulder weight
10	Bunch length	BuLe	Cm	Digital caliper
11	Bunch width	BuWi	Cm	Digital caliper
12	The ratio of bunch length to bunch width	BuLetoBuWi	Cm	Digital caliper
13	Berry diameter	BeD	Mm	Digital caliper
14	Berry weight	Bewe	G	Digital caliper
15	Berry length	BeL	Mm	Digital caliper
16	Berry width	BeW	Mm	Digital caliper
17	The ratio of berry length to width	BeLtoBeW	Mm	Digital caliper
18	Length of the tail of bunch	LTB	Cm	Digital caliper
19	Length of the tail of berry	LTBe	Mm	Digital caliper
20	Pedicel weight	PeWe	g	Digital scale
21	°Brix	B	°Brix	Refractometer
22	Dried fruit weight of bunch	DrFrWeB	g	Digital scale
23	Rachis weight	RchWe	g	Digital scale

Table 3. (*Continued*). List of quantitative and qualitative traits and their measurement methods in grapevine genotypes and cultivars, based on the descriptors of OIV (2007), Bioversity International, and UPOV (2008).

Row	Trait		Abbreviation	Unit	Measurement method
24	peduncle weight	wood	PeWWe	g	Digital scale
25	Dried fruit weight of peduncle		DFrWePe	G	Digital scale
26	Berry (Score)	shape	BeSh	Score	1= Oblong 2= Narrow elliptic 3= Elliptic 4= Round 5= Oblate 6= Ovate 7= Obtuse-ovate 8= Obovate 9= Arched
27	Bunch density		BC	Score	3= Open, 5= Medium, 7= Tight, 9= Very tight
28	Skin color		SC	Score	1= Green-yellow, 2= Rose, 3= Red, 4= Red Gray, 5= Dark red-violet, 6= Blue-black
29	Skin thickness		STh	Score	3= Thin, 5= Medium, 7= Thick
30	Berry hardness		BHa	Score	1=Soft, 2=Slightly hard, 3=Hard
31	Juiciness of berry flesh		Bju	Score	1= Low water, 2= Slightly watery, 3= Very watery
32	Separating from the pedicel		SeFr	Score	1= Hard, 2= Fairly easy, 3= Very easy

OIV: International Organization of the Vine and Wine (www.oiv.int), Bioversity International (www.Bioversityinternational.org), UPOV: International Union for the Protection of New Varieties of Plants (www.upov.int).

RESULTS AND DISCUSSION

Descriptive statistics and frequency distribution of traits

For the traits analyzed, the minimum, maximum, mean, standard deviation (SD), and coefficient of variation (CV) were calculated for quantitative traits and are presented in (Table 4). The results showed a high level of variability for some quantitative traits, such as skin color (CV = 88.58%), pedicel weight (CV = 58.99%), rachis weight (CV = 57.71%) berry weight (CV = 56.16%), the ratio of bunch weight to bunch shoulder weight (CV = 55.22%), dried fruit weight of the bunch (CV = 54.61%), bunch shoulder weight (CV = 49.06%), bunch weight (CV = 43.89%), the ratio of berry length to berry width (CV = 41.14%), length of the tail of bunch (CV = 43.44%) (Table 4).

Qualitative traits were summarized using the mode (the most frequent category) instead of the mean to better represent the nature of categorical variables. Green-yellow skin color was the most frequent among the cultivars, while the least frequent skin color was dark blue, observed in the genotypes “*Rasheh Ilam*,” “*Rasheh Vargache*,” and the “*GD4 Chamanar*” (Fig. 2). The highest pedicel weight was found in the cultivar “*Asgari Ilam*” (0.04 g). The highest bunch shoulder weight was observed in “*GF3 Kolm*” (64.28 g), while the lowest was in “*Sahebi Sefid Vargache*” (10.67 g). The highest berry weight was found in the “*GF2 Kolm*” (3.47 g), and the lowest in “*Asgari Sefid Chamanar*” (0.51 g). The highest ratio of bunch weight to bunch shoulder weight was observed in “*GD Chamanar*” (20.62 g), while the lowest was in “*GD4 Chamanar*” (3.03 g). The highest dried fruit weight of the bunch was

observed in “*Shahani Sefid Vargache*” (70.30 g), and the lowest in “*GFI Kolm*” (13.86 g) (Fig. 2).

Mirfatah et al. (2024) reported similar findings, supporting the results obtained in this study, which showed high diversity in traits such as seed weight, seed length, bunch weight, pedicel weight, dried bunch shoulder weight, berry weight, the ratio of rachis weight to bunch weight, fresh bunch shoulder weight, rachis weight, the ratio of bunch weight to peduncle weight, bunch shoulder weight, peduncle weight, and the ratio of peduncle weight to bunch shoulder weight among the cultivars and genotypes. The results also align with those of Kazemi et al. (2024), who observed high coefficients of variation in traits such as berry skin color, berry weight, bunch weight, bunch shoulder weight, berry size, and bunch size. According to the findings of Rasouli et al. (2014), high variability was observed in traits such as skin color, pedicel weight, berry weight, bunch shoulder weight, bunch weight, peduncle length, and berry shape among the genotypes, supporting the findings obtained in this research. Additionally, Erfani-Moghadam et al. (2008) reported considerable variation in traits such as bunch weight, number of berries per bunch, and berry weight among grape genotypes, findings that are in agreement with the results of the present study. This consistency, despite the climatic differences between the studied regions, may be due to the genetic similarity of the cultivars and genotypes. Such a level of diversity can be utilized for selecting cultivars for further research, breeding programs, and the introduction of new cultivars well adapted to the region.

To assess which traits exhibited the highest variation, the frequency distribution and range of both quantitative and qualitative traits were analyzed. The results revealed that skin color (CV = 88.58%), pedicel length (CV = 58.99%), pedicel weight (CV = 58.99%), rachis weight (CV = 57.71%), berry weight (CV = 56.16%) and the ratio of bunch weight to peduncle weight (CV = 55.22%) exhibited the greatest variability (Fig. 2, Table 4).

In terms of skin color, most of the studied groups exhibited a green-yellow hue, which may be attributed to the genetic traits of the genotypes, climatic conditions, or market preferences for such colors (Fig. 2A). The dried fruit weight of the bunch in most cultivars ranged between 10 and 30 g, which were commonly observed across different groups (Fig. 2B). Peduncle weight varied between 0.5 and 3.5 g, with all genotypes from the Chamanar region falling within this range (Fig. 2C). In most genotypes especially all genotypes from Kolm located in the Badreh region, Ilam province, the ratio of bunch weight to peduncle weight generally ranged between 3 and 10 (Fig. 2D). Pedicel weight in most genotypes ranged between 0.01 and 0.02 g, with the Asgari cultivar from Ilam showing the highest value (0.04 g) (Fig. 2E). Berry weight in most genotypes ranged between 0.5 and 1.5 g (Fig. 2F). Since the observed variation in trait frequency charts did not follow a consistent pattern specific to any particular region, this variability is more likely due to the inherent genetic differences among the genotypes rather than to environmental influences (Antoin et al., 2021).

These findings are consistent with those reported by Rasouli and Kalvandi (2022), who reported the highest levels of diversity in traits such as skin color, pedicel weight, berry weight, bunch weight, rachis weight, and peduncle weight. Given the observed variation in the evaluated traits, those exhibiting high diversity can be effectively exploited for more precise statistical analysis and for the precise assessment of cultivars and genotypes (Bodor et al., 2003).

Table 4. Descriptive statistics including minimum, maximum, mean, standard deviation, variance, and coefficient of variation for quantitative and qualitative traits of grape cultivars and genotypes.

Descriptive statistics							
	N	Minimum	Maximum	Mean	Std. Deviation	Variance	%CV
Leaf width(cm)	22	6.78	18.72	12.8295	3.55585	12.644	27.72
Leaf length(cm)	22	5.95	19.21	11.7800	4.00013	16.001	33.96
Leaf area(mm ²)	22	195.64	596.32	370.9068	114.83746	13187.64	30.96
Fruit ripening time (Day)	22	156.00	260.00	213.8182	29.83229	889.965	13.95
Bunch per vine (No.)	22	25.00	100.00	49.5455	15.18999	230.736	30.66
Average yield (kg)	22	25.00	60.00	34.8636	10.02043	100.409	28.74
Bunch weight(g)	22	95.64	506.21	234.6982	103.01195	10611.46	43.89
Bunch shoulder weight(g)	22	10.67	64.28	30.7727	15.09741	227.932	49.06
Ratio of bunch weight to bunch shoulder weight(g)	22	3.03	20.62	9.1309	5.04167	25.418	55.22
Bunch length(cm)	22	8.20	45.20	23.0541	9.08719	82.577	39.42
Bunch width(cm)	22	5.10	17.42	9.6300	3.27073	10.698	33.96
The ratio of Bunch length to bunch width(cm)	22	1.02	4.16	2.5023	0.89258	0.797	35.67
Berry diameter(mm)	22	6.00	19.00	11.1382	2.63769	6.957	23.68
Berry weight(g)	22	0.51	3.47	1.5741	0.88398	0.781	56.16
Berry length(mm)	22	8.00	22.30	14.6682	4.34033	18.838	29.59
Berry width(mm)	22	1.48	19.30	10.6036	3.61712	13.084	34.11
The ratio of berry length to width (mm)	22	0.10	2.50	1.2432	0.51147	0.262	41.14
Length of the tail of bunch(cm)	22	2.61	15.57	8.4277	3.66099	13.403	43.44
Length of the tail of berry(mm)	22	4.30	15.00	9.1123	2.66788	7.118	29.28
Pedicle weight(g)	22	0.01	0.04	0.0155	0.00912	0.000	58.99
°Brix	22	14.32	23.12	19.7659	1.83841	3.380	9.30
Dried fruit weight of bunch(g)	22	13.86	70.30	30.0000	16.38351	268.419	54.61
Rachis weight(g)	22	4.20	23.62	12.9500	5.27510	27.827	40.73
peduncle wood weight (g)	22	0.84	7.40	3.0445	1.75713	3.088	57.71
Dried fruit weight of peduncle(g)	22	3.12	13.40	7.5095	2.88730	8.336	38.45
Berry shape (Score)	22	2.00	6.00	4.5455	1.10096	1.212	24.22
Bunch density (Score)	22	3.00	7.00	4.8182	1.62235	2.632	33.67
Skin color (Score)	22	1.00	6.00	1.9545	1.73143	2.998	88.58
Skin thickness (Score)	22	2.00	5.00	4.2273	1.06600	1.136	25.22
Berry hardness (Score)	22	1.00	3.00	1.8636	0.46756	0.219	25.09
Juiciness of berry flesh (Score)	22	2.00	3.00	2.1364	0.35125	0.123	16.44
Separating from the pedicel (Score)	22	1.00	3.00	1.8636	0.56023	0.314	30.06
Berry size (Score)	22	3.00	7.00	4.7273	1.12045	1.255	23.70

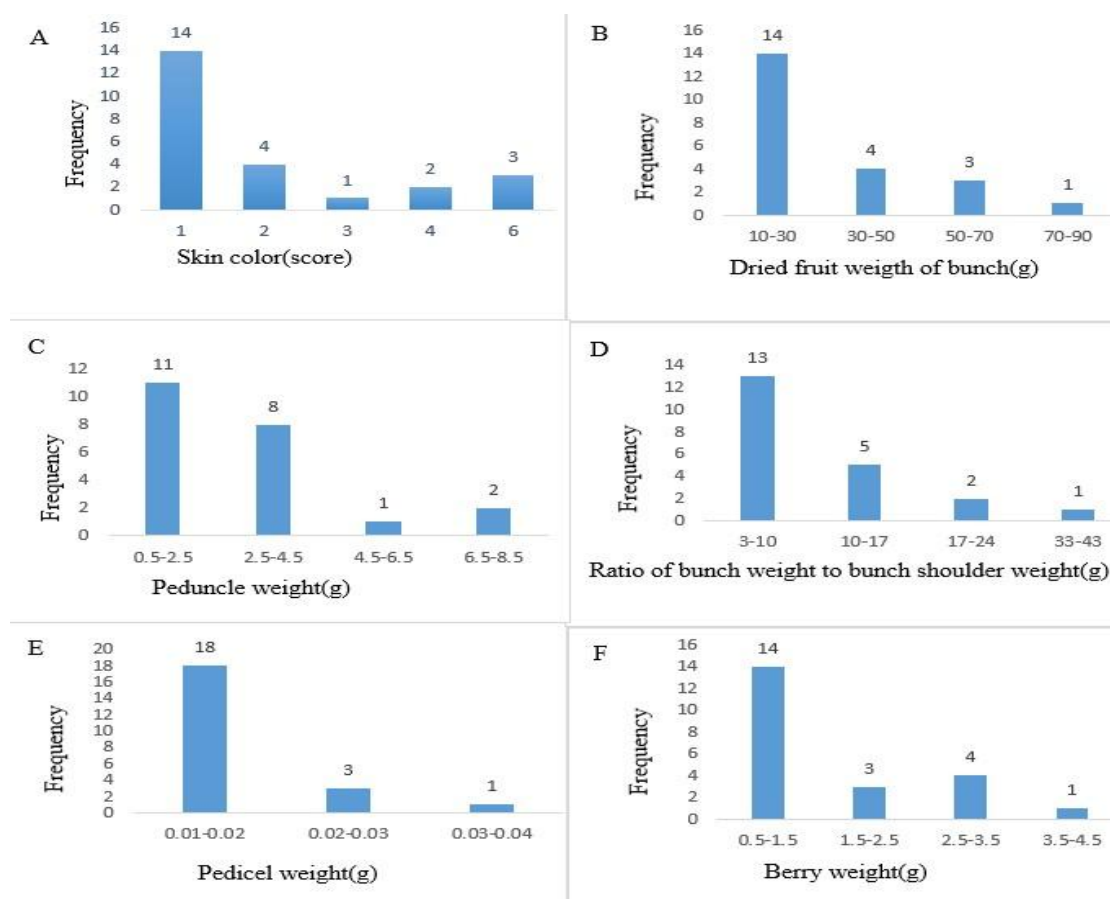


Fig. 2. Frequency distribution of selected traits in different cultivars and genotypes of grapes. (A) Frequency distribution of Skin color based on the following codes: 1 = Green-yellow, 2 = Rose, 3 = Red, 4 = Red-gray, 5 = Dark red-violet, 6 = Blue-black. (B) Frequency distribution of dried fruit weight of bunches based on the following ranges: 10-30 = Low, 30-50 = Medium, 50-70 = High, 70-90 = Very high. (C) Frequency distribution of Length of the tail of bunch based on the following ranges: 10-30 = Low, 30-50 = Medium, 50-70 = High, 70-90 = Very high. (D) Frequency distribution of the ratio of bunch weight to bunch shoulder weight based on the following ranges: 10-13 = Low, 13-17 = Moderate, 17-24 = High, 33-43 = Very high. (E) Frequency distribution of pedicel weight based on the following ranges: 0.01-0.02 = Light, 0.02-0.03 = Medium, 0.03-0.04 = Heavy. (F) Frequency distribution of berry weight based on the following ranges: 0.5-1.5 = Very light, 1.5-2.5 = Light, 2.5-3.5 = Medium, 3.5-4.5 = Heavy.

Correlation of traits

For brevity, the correlation table is not included in this manuscript. However, the results indicated significant associations among the studied traits. A strong significant positive correlation was found between berry diameter and berry weight ($r = 0.756$), as well as between dried fruit weight of bunch and rachis weight ($r = 0.801$). Leaf width showed moderate positive correlations between leaf length ($r = 0.554$), fruit sugar content ($r = 0.673$), and separating from the pedicel ($r = 0.510$). Conversely, leaf width was moderately negatively correlated with skin color ($r = -0.550$). Leaf length exhibited significant positive correlations with fruit sugar content ($r = 0.548$), dried fruit weight of bunch ($r = 0.554$), dried fruit weight of the peduncle ($r = 0.639$), and bunch density ($r = 0.692$), as well as a moderate positive correlation with bunch width ($r = 0.482$). Significant negative correlations were found between leaf length and fruit ripening time ($r = -0.595$) and berry size ($r = -0.619$). Fruit ripening time positively correlated with the ratio of bunch length to width ($r = 0.540$) and berry length ($r = 0.612$).

Maintaining an appropriate leaf area per unit of fruit weight is crucial for vineyard management and is necessary for grapevine growth (Auzmendi & Holzapfel, 2016). Cultivars such as “Zarde Vargache”, “Shahani Sefid Vargache”, and the genotypes of Kolm exhibited greater leaf length and width compared to others. These cultivars and genotypes also showed higher bunch density, dried fruit weight of bunch, bunch shoulder weight, rachis weight, and fruit sugar content. Additionally, their fruit ripening times were close to the average (213.82 days), as reported in the descriptive statistics table. The number of days was calculated based on the Gregorian calendar. The average yield showed a significant negative correlation with berry width ($r = -0.549$) and a significant positive correlation with separation from the pedicel ($r = 0.531$). Cultivars such as “Asgari Sefid Vargache” and the genotype “GD3 Chamanar”, which had higher average yields, exhibited smaller berry widths and easier separation from the pedicel. Bunch weight correlated positively with bunch shoulder weight ($r = 0.517$), and dried fruit weight of peduncle ($r = 0.512$), but negatively with berry hardness ($r = -0.532$) and berry width ($r = -0.503$). Cultivars such as “Perlette” and the genotype “GD3 Chamanar”, with higher bunch weights, also had notably higher bunch shoulder weights and dried fruit weights compared to others.

The findings of this study are consistent with the results reported by Mirfatah et al. (2024) and the research conducted by Rasouli and Kalvandi (2022). The bunch shoulder weight exhibited a significant positive correlation with bunch length ($r = 0.541$), bunch width ($r = 0.512$), berry diameter ($r = 0.532$), and berry weight ($r = 0.558$). However, it showed a significant negative correlation with the ratio of bunch weight to bunch shoulder weight ($r = -0.638$). The genotype “GF3 Kolm”, which had the highest bunch shoulder weight among all cultivars and genotypes, also presented the lowest ratio of bunch weight to bunch shoulder weight and the greatest bunch length, bunch width, and berry weight.

The ratio of bunch weight to bunch shoulder weight showed significant negative correlations with berry diameter ($r = -0.564$), berry weight ($r = -0.611$), and berry length ($r = -0.585$). This suggests that as bunch weight increases, bunch shoulder weight also increases, leading to a reduced ratio of bunch weight to bunch shoulder weight. Such bunches, like those of the genotypes “GD3 Chamanar” and “GF3 Kolm” examined in this study, tended to have larger berries in diameter, length, width, and weight. These results also confirm the conclusions drawn by Rasouli and Kalvandi (2022).

Bunch length showed significant positive correlations with bunch width ($r = 0.572$), the ratio of bunch length to bunch width ($r = 0.522$), and juiciness of berry flesh ($r = 0.493$). A significant positive correlation was observed between bunch width and fruit sugar content ($r = 0.591$). The genotypes “GF1 Kolm”, “GF2 Kolm”, and “GF3 Kolm”, which exhibited the greatest bunch lengths among the studied cultivars and genotypes, also showed high bunch widths. The berries were found to have higher juiciness and fruit sugar content. The ratio of bunch length to bunch width had a significant negative correlation with dried fruit weight of the bunch ($r = -0.548$). For instance, cultivars such as “Fakhrii Vargache” and “Asgari Sefid Chamanar”, which exhibited the highest ratio of bunch length to bunch width, produced less diverse bunches and had lower dried fruit weight of the bunch.

Berry diameter showed a significant positive correlation with berry weight ($r = 0.756$), berry width ($r = 0.663$). Berry weight was also significantly and positively correlated with berry length ($r = 0.599$). These results are in line with the findings of El-Ouakadi and Hajjaj (2019), who reported strong correlations between berry diameter and berry length, width, and weight.

Fruit sugar content showed significant positive correlations with bunch density ($r = 0.569$). Berry shape was positively correlated with skin thickness ($r = 0.539$). Berry hardness showed significant negative correlations with separation from the pedicel ($r = -0.620$). This

indicates that genotypes with thicker skin typically have less juice and more difficulty in pedicel separation. The Pearson correlation results of this study are consistent with those reported by Ekhvaia and Akhalkatsi (2010), and Rasouli and Kalvandi (2022).

Principal Component Analysis (PCA)

To determine the variation of each trait explained by the factors, principal component analysis was performed using ten principal components, which together accounted for 87.18% of the total variance (Table 5). The contribution of each factor to the variance was expressed as a percentage. Among the components, the first and second principal components had the highest contributions, together explaining 33.50% of the total variance.

Traits such as leaf length, leaf width, bunch weight, bunch width, fruit sugar content, and dried fruit weight of the bunch, rachis weight, and dried fruit weight of the peduncle, bunch density, and separation from the pedicel were grouped under the first principal component (PC1), which accounted for 19.47% of the total variance. This component can be interpreted as representing the structural traits of the bunch and fruit.

Traits such as fruit ripening time, bunch shoulder weight, bunch length, berry diameter, berry length, berry weight, and berry width were grouped under the second principal component (PC2), which accounted for 14.03% of the total variance. This component can be interpreted as representing bunch and berry traits. The first two principal components together explained 33.50% of the cumulative variance and had the most significant impact on the discrimination of cultivars and genotypes. Similarly, in the study by Rasouli et al. (2014), the first two components, mainly associated with bunch and berry traits, explained 32.54% of the total variance.

The third principal component (PC3), which explained 10.70% of the total variance, included traits such as the ratio of berry length to width, length of the tail of the berry and the juiciness of berry flesh. This component can be regarded as the berry component. Along with the first two components, PC3 contributed to 44.20% of the cumulative variance. In the study conducted by Hashemzahi et al. (2010) on 20 grape cultivars, the first three principal components accounted for 34.79% of the total variance.

The fourth principal component (PC4) accounted for 9.30% of the variance and included traits such as leaf area, average yield per vine, and skin thickness. The fifth principal component (PC5), which explained 8.09% of the variance, included traits such as pedicel weight and berry shape. The sixth component (PC6) was associated with the ratio of bunch length to bunch width and accounted for 6.86% of the total variance. The seventh component (PC7), representing the bunch per vine trait, explained 6.20% of the variance. No significant trait was associated with the eighth component (PC8). The ninth component (PC9), which explained 4.20% of the variance, was associated with berry hardness. In the study by Chitwood et al. (2014), berry width, berry weight, and bunch weight contributed most to the first principal component, which explained 44.16% of the total variance. Most similar studies on grape morphological traits have shown that berry- and bunch- related traits have a stronger contribute more strongly to variance. Traits such as berry weight, berry length and width, bunch weight and bunch shoulder weight, and the ratio of berry length to berry width can be utilized in grape breeding programs. It has also been widely reported in morphological studies of grapes that the first two principal components primarily represent bunch and berry traits (Rasouli et al., 2014; Rasouli & Kalvandi, 2022; Mirfatah et al., 2024). The traits grouped under the first component exhibited strong to moderate positive correlations with each other (Fig. 3). As reported by Kazemi et al. (2024), the ratio of berry length to width was loaded onto the first component, whereas traits such as dried berry weight, shoulder length, and number of berries per bunch were associated with the second component; together, these

components explained 27.17% of the total variance. These findings indicate that genetic diversity can be effectively assessed using morphological traits. Furthermore, correlations among traits provide a cost-effective and practical approach for breeding programs. For instance, when one trait is highly correlated with another, it can serve as a reliable predictor of the latter (Erfani-Moghadam et al., 2016).

Table 5. Eigenvalues, percentage of variance explained, and cumulative variance explained by the first 10 principal components in this study.

Initial Eigenvalues			
Factor	Eigenvalues	Eigenvalues to percent variance	Percentage of variance cumulative
1	6.55	19.85	19.85
2	4.321	13.095	32.945
3	3.66	11.091	44.036
4	3.061	9.276	53.312
5	2.663	8.071	61.383
6	2.25	6.818	68.201
7	2.023	6.131	74.332
8	1.652	5.005	79.337
9	1.427	4.324	83.66
10	1.133	3.432	87.092

Cluster Analysis

Cluster analysis based on the studied traits was conducted using Ward's method, resulting in the grouping of cultivars and genotypes into four main clusters at a Euclidean distance of 5.

Group 1: The first cluster comprised the cultivars and genotypes “*Rasheh Ilam*”, “*Asgari Ilam*”, “*Rasheh Vargache*”, “*Fakhri Vargache*”, “*Zarde Vargache*”, “*Bidaneh Sefid Vargache*”, and “*GD1 Chamanar*”. These cultivars and genotypes shared similar leaf, bunch, and berry traits. Among them, “*Zarde Vargache*” and “*Bidaneh Sefid Vargache*” exhibited the highest number of bunches per vine as well as the greatest weights of bunches and bunch shoulders. Regarding fruit ripening time, this group was considered mid- season ripening. The average yield ranged from 30 to 40 kg per vine, with “*Zarde Vargache*” achieving the highest yield at 45 kg per vine. All cultivars and genotypes within this cluster displayed moderate fruit sugar content (18–20%).

Group 2: The next cluster comprised the genotypes and cultivar “*GD4 Chamanar*”, “*GF3 Kolm*”, and “*Perlette*”. Among them, the cultivar “*Perlette*” exhibited the highest average yield of 35 kg per vine. Despite originating from different regions, these genotypes and cultivars clustered together based on traits such as leaf width, leaf length, leaf area, and fruit ripening time. They possessed a moderate leaf area (350–450 mm²) and were classified as mid- season ripening. Their yield (30–40 kg per vine) was comparable to that of Group 1. Additionally, they clustered based on berry diameter and pedicel length, exhibiting moderate berry diameter (11–14 mm) and moderate pedicel length (9–12 mm). The genotype “*GD4 Chamanar*” and cultivar “*Perlette*” displayed moderate sugar content (18–20%), whereas the genotype “*GF3 Kolm*” showed very high sugar content (23.12%). All genotypes in this group had green-yellow skin color.

Group 3: Another cluster included the cultivars and genotype “*Asgari Sefid Vargache*”, “*GF2 Kolm*”, “*Shahani Sefid Vargache*”, and “*Sahebi Sefid Vargache*”. These genotypes and

cultivars were grouped together based on leaf area, exhibiting the largest values among all studied cultivars (500–600 mm²). Except for “Sahebi Sefid Vargache”, which was classified as late- season ripening, all members of this cluster were categorized as mid- season ripening. Yield performance for this group was moderate, ranging from 45 to 55 kg per vine. Regarding fruit sugar content, the genotype “*GF2 Kolm*” exhibited a relatively high °Brix value (22.83%), whereas the other three cultivars, all from the Vargache region, showed moderate sugar content (18–20%). The predominant berry shape within this group was ovoid) egg-shaped) .

Group 4: This cluster included cultivars and genotypes such as “*Asgari Sefid Chamanar*”, “*GD2 Chamanar*”, “*Yaghooti Vargache*”, “*Yaghooti Ilam*”, “*Yaghooti Farkhinvand*”, “*GD3 Chamanar*”, “*GD4 Chamanar*”, and “*GF1 Kolm*”. The majority of genotypes in this group originated from the Chamanar region, located within the semi-arid zone of Ilam province. The genotypes in this group were similar in fruit traits and were primarily classified as early-season ripening, with “*Yaghooti Ilam*” identified as the earliest- season ripening among them. The lowest yield within this cluster was recorded for the genotype “*GD2 Chamanar*” (25 kg per vine), whereas the genotype “*GD3 Chamanar*” exhibited the highest yield (60 kg per vine). The highest sugar content in this group was recorded for the genotype “*GF1 Kolm*” (21.53%), while the remaining cultivars exhibited moderate °Brix values (18–20%). All genotypes in this group possessed soft flesh texture and high juiciness.

The obtained results in this study were consistent with those of Rasouli and Kalvandi. (2022), which performed cluster analysis on 31 morphological traits across 36 different grape genotypes. In their analysis, the genotypes were grouped into four clusters at a Euclidean distance of 5, with key discriminating factors including bunch weight, fruit sugar content, leaf width, and leaf length (Rasouli & Kalvandi, 2022). According to Kazemi et al. (2024), who studied cultivars and genotypes from Khuzestan, cluster analysis divided the genotypes into nine groups and demonstrated significant differences among them in growth and reproductive traits, particularly with respect to superior characteristics contributing to the observed morphological diversity. The variations observed in this study can be attributed to differences in traits among the genotypes and cultivars.

Moreover, the findings of this research align with those of Mirfatah et al. (2024), who conducted cluster analysis on 84 grape cultivars from Markazi province. In their study, genotypes were grouped based on traits such as fruit characteristics, bunch density, and berry size within the bunch, average yield, and leaf area. Comparable results were also reported in studies by Hashemzehi et al. (2010), Chitwood et al. (2014), Rasouli et al. (2014), and Erfani-Moghadam et al. (2016), despite differences in the regions, climatic conditions, and growth substrates of the cultivars examined.

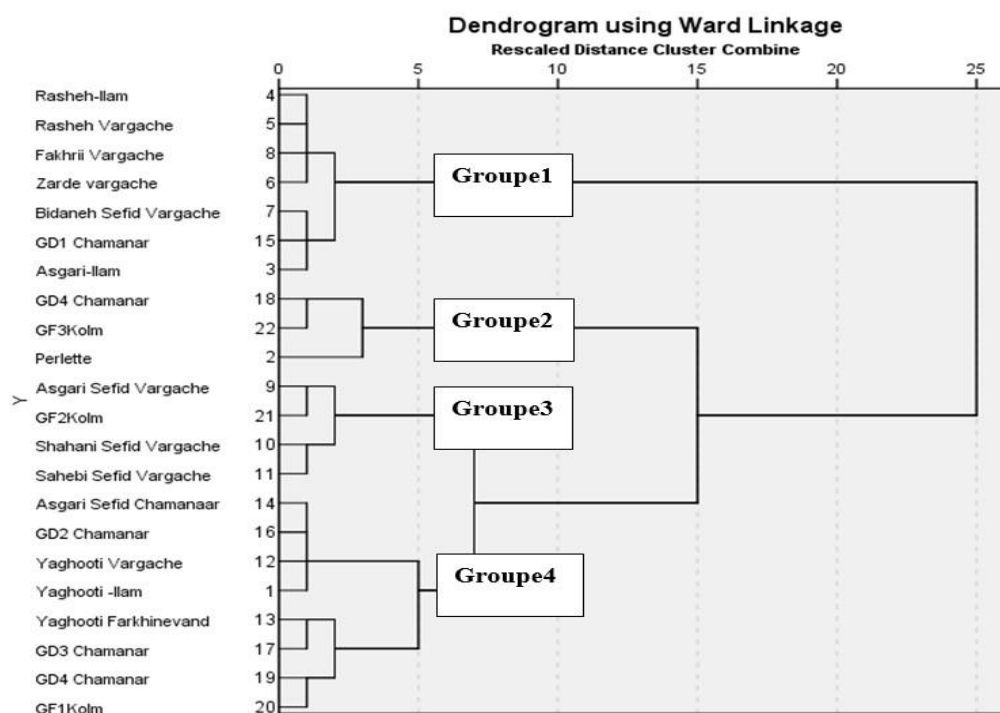


Fig. 3. Dendrogram illustrating the relationship among 22 grape cultivars and genotypes from vineyards in Ilam province located in west of Iran, based on studied traits using cluster analysis by Ward's method.

CONCLUSIONS

The aim of this research was to investigate the traits affecting the performance of selected cultivars and genotypes from various regions of Ilam province. The results indicated that the highest diversity was observed in traits such as leaf area, leaf length and width, fruit ripening time, average yield, bunch weight, bunch shoulder weight, bunch length, and berry traits including berry shape, berry diameter and weight, berry hardness, and juiciness. By combining superior traits from multiple cultivars, breeding programs can identify genotypes and cultivars well suited to the region and develop high-performing vineyards.

In this study, the genotype “*Zarde Vargache*” from the first group and the genotype “*GD3 Chamanar*” from Chamanar, located in the Malekshahi region of Ilam province, demonstrated the highest performance and can be introduced as cultivars well suited to the region. Additionally, the genotypes “*GF1 Kolm*”, “*GF2 Kolm*”, and “*GF3 Kolm*” from Kolm located in the Badreh region of Ilam province, exhibited higher fruit sugar content compared to other cultivars and genotypes, and can be recommended as table grapes with high market appeal, as well as potential cultivars.

These genotypes all exhibit a green-yellow skin color, moderate bunch density, high leaf area, and larger berry diameter and weight compared to other cultivars and genotypes. To improve production and diversity in the vineyards of Ilam province, crossing these cultivars and implementing structured breeding programs may lead to the development of cultivars with enhanced fruit quality and superior market performance.

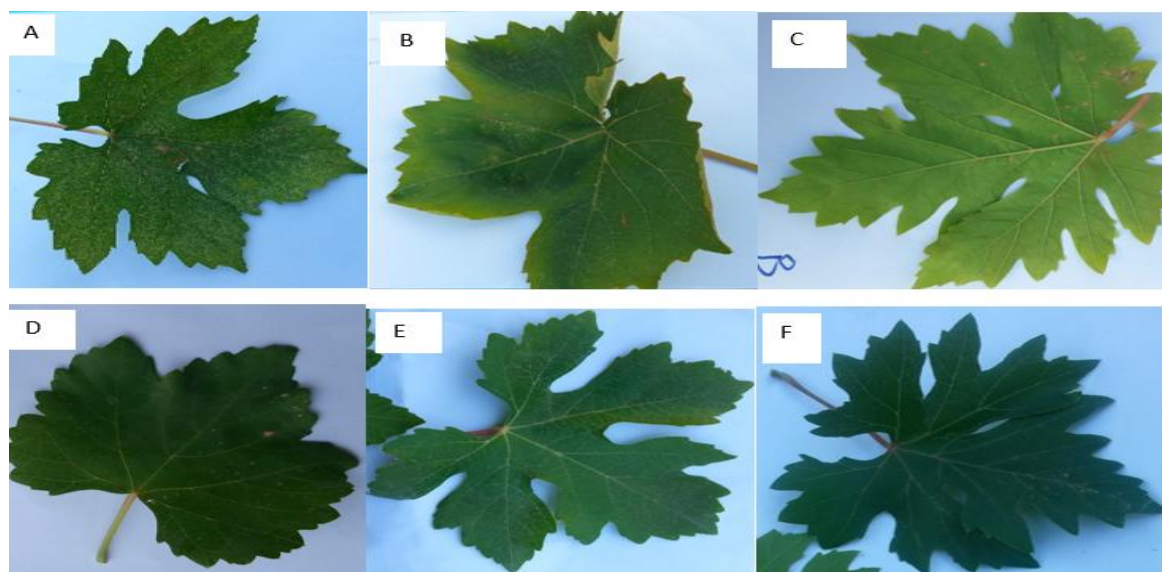


Fig. 4. Leaves of cultivars and genotypes from vineyards in Ilam province, located in western Iran, including: “Fakhrii Vergeche” (A), “Shahani Sefid vargache” (B), “Zard Vergeche” (C), “GD Chamanar” (D), “GF2 Kolm” (E), and “GD2 Chamanar” (F).

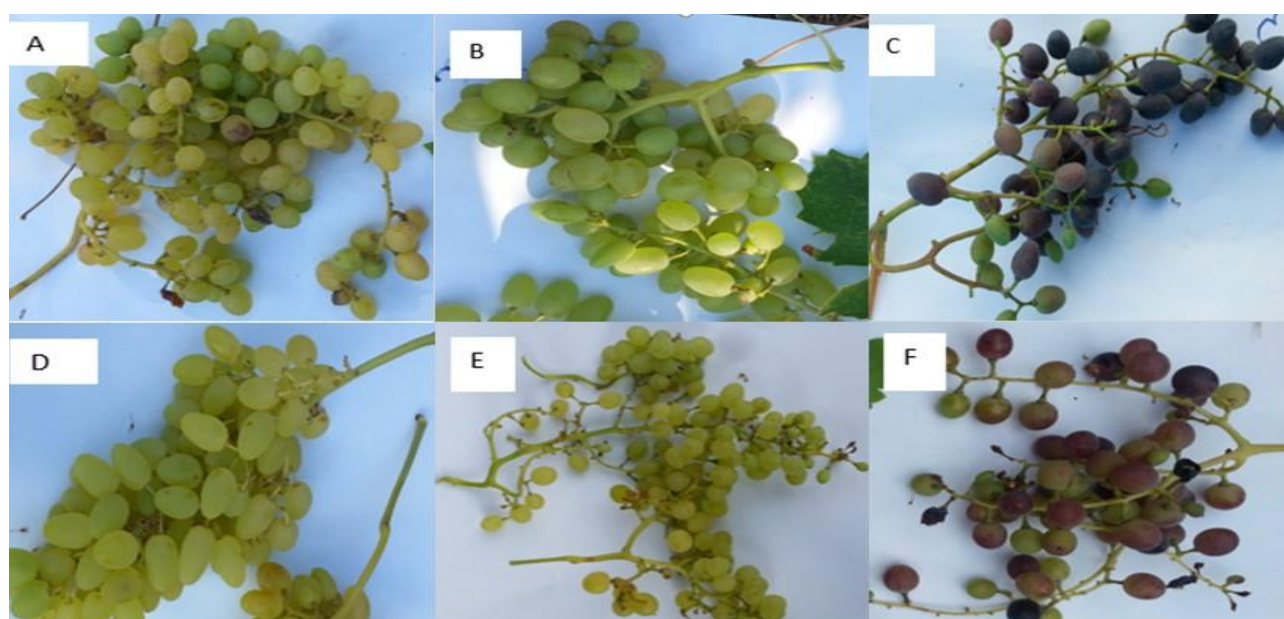


Fig. 5. Bunches of some grape cultivars and genotypes from vineyards in Ilam province, located in western Iran, including: “Sahebi Sefid Vargache” (A), “Bidaneh Sefid Vargache” (B), “Rasheh Vargache” (C), “Zarde Vargache” (D), “Asgari Sefid Chamanar” (E), and “GD2 Chamanar” (F).

Conflict of interest

The authors (Z. Sadeghi-nejad, M. Rasouli, J. Erfani-Moghadam and R. Karimi) declare that they have no competing interest.

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