Original scientific paper
DOI: /10.5513/JCEA01/27.3.5025
Journal of Central European Agriculture, 2026, 27(3), p.693-708

Seed morphometry as a tool for discriminating the diversity of Moroccan grapevine

Nouhaila DIHAZ[1], Salama EL FATEHI[1], Hanan EL AOU-OUAD[2], Anass BEN MOULA[3], Widad BEN-ZIANE[1], Abdelhalim CHMARKHI[1], Younes HMIMSA[1] (✉)

[1] TEDAEEP Team Research, Abdelmalek Essaâdi University – (UAE-FPL), Polydisciplinary Faculty of Larache, B.P. 745 Larache, 92004., Morocco

[2] Ecology and Environment Laboratory, Faculty of Science Ben M'sik, University Hassan II, Casablanca 20000, Morocco

[3] Plant, Microbial, Marine, and Precision Agriculture Biotechnology research team; Abdelmalek Essaadi University – (UAE-FPL), Larache, 92004, Morocco

✉ Corresponding author: y.hmimsa@uae.ac.ma

Received: September 25, 2025; accepted: February 5, 2026

ABSTRACT

Grapevine seeds exhibit a high degree of polymorphism. Accordingly, they have been utilized for genus *Vitis* taxonomy and generally, their phenotypic traits are used to describe *Vitis vinifera* L. varieties. To study the phenotypic diversity of grapevine seeds using linear morphometry, 540 seeds from 27 indigenous Moroccan grapevine varieties were sampled. Eleven linear morphometric parameters were used to characterize seed shape, while four indices (aspect ratio, circularity, roundness, and solidity) were employed to describe seed form. The results demonstrated that the selected morphometric measurements have strong discriminative power. Their application to seeds from indigenous Moroccan varieties revealed marked inter-varietal and intra-varietal variability. For all varieties, one-way and two-way analyses of variance (ANOVA) showed highly significant differences with elevated F-values, indicating a high rate of variability both within and among varieties. Principal component analysis further revealed that grapevine varieties from the Western Rif exhibit greater intra-seed variability compared to those from the Middle and High Atlas regions. In contrast, seeds from the latter regions are generally bigger, wider, and more circular and rounded. These findings support the hypothesis that grape seeds display distinct phenotypic patterns linked to their geographical origin.

Keywords: *Vitis vinifera* L., local varieties, shape characteristics, seed form, variability

INTRODUCTION

Grape (*Vitis vinifera* L. ssp. *vinifera*) is among the most ancient fruit-bearing plants in the Old World, and alongside the olive, fig, pomegranate and date palm, belongs to the oldest groups of domesticated fruit trees (Martín-Gómez et al., 2020). Nowadays, *Vitis vinifera* L. is one of the most economically significant fruit crops worldwide, with a cultivated area of about 7.5 million hectares globally. Beyond its primary use in wine production, grapevine is also used for the production of fresh grapes, raisins, and juice, as well as for the extraction of tannins and antioxidants (Gramaje et al., 2018). Furthermore, grapevines are frequently utilized in climate change research and serve as a well-studied biological model of perennial plants (Sadras and Moran, 2013). The history and cultivation methods of the vineyard have greatly impacted the genetic diversity found in grapevines today (This et al., 2006). This diversity is important in terms of both grape varieties and clones. However, the variation between grape varieties (inter-varietal) is more important than the variation between clones (intra-varietal) regarding both agro-morphological traits and molecular diversity (Boursiquot et al., 2007). The in-

ternational catalogue of *Vitis* varieties contains 21,045 names, with 12 250 specified for *V. vinifera*. However, a noteworthy number within these varieties are synonyms and homonyms (Galet, 1990). Additionally, the number of grape varieties worldwide is estimated at 6,000 for the *V. vinifera* species alone (Galet, 2015).

One of the world's greatest challenges today is genetic erosion, which is leading to the loss of diversity among grapevine varieties. In contrast to this genetic erosion, global grape consumption has increased in recent years. In 2021, table grape consumption was estimated at 30.1 million tonnes, representing an increase of 5% compared to 2020. This growing demand necessitates considerable effort to ensure the conservation, evaluation, and selection of the most productive and well-adapted varieties (Musayev and Akparov, 2013; OIV, 2021). Furthermore, the rising global demand for grapes is contributing to the gradual disappearance of wide traditional varieties. Consequently, many farmers are increasingly looking to cultivate contemporary varieties and adopt modern agricultural practices to achieve higher levels of production. However, traditional varieties fulfill a key role in cultivation and breeding, they are more resilient and better adapted to local conditions in some regions; according to certain research, in the presence of long-term natural and artificial selection pressures including climate and soil type, amongst various other factors, traditional varieties exhibit remarkable resilience to climate change (Ma et al., 2022; Lei et al., 2009; Min et al., 2011). In Morocco, traditional grapevine varieties exhibit a remarkable adaptation to local climatic conditions with minimal intervention. Despite this, they display significant varietal diversity, which remains largely underappreciated due to the lack of comprehensive pomological and morphological characterization. Consequently, a vital component of the country's genetic heritage is not fully recognized, and both its evaluation and documentation are still incomplete (El Oualkadi and Hajjaj, 2019).

To analyze this genetic diversity and identify grapevine varieties, phenotypic characterization is essential (Abdel-Hamed et al., 2020; El Fatehi et al., 2021a; Hmimsa et al., 2023, 2021). In this respect, modern morphometric techniques and statistical analyses offer botanists an additional way to capture and quantify diversity. Morphological data have become increasingly utilized in the study of evolution in multiple disciplines, including the study of morphological variation. Moreover, the combination of morphological and statistical tools is an added value to promote a more appropriate morphological evaluation in botanical research (Toujgani et al., 2024; Kassout et al., 2023; El Fatehi et al., 2021b; Martín-Gómez et al., 2020; Christodoulou et al., 2020; Saadaoui et al., 2015; Gardner et al., 2012).

The study of seeds and fruits is an excellent phenotypic descriptor that may indicate variations in climate, ecology, and society, as well as providing clues about history, evolution, and the domestication of plants for human use (Milanesi et al., 2014). Historically, for almond features, the only method of cultivar discrimination was morphological evaluation, which is essential for cultivar selection. Based on phenotypic observations, this evaluation covers traits of the fig, nuts, and kernels, such as weight, thickness, and length/width ratio, as well as traits of the fruits, leaves, flowering, and harvest time (Toujgani et al., 2024; Mougiou et al., 2023).

In viticulture, grape seeds are highly polymorphic. The morphology of seeds can vary significantly due to either genetic or environmental factors (Cervantes et al., 2025); therefore, the utilization of grape seeds in the reconstruction of trade and geographical routes of grapevine varieties. This methodology has facilitated a comprehensive understanding of domestication and enabled the taxonomy differentiation within the genus *Vitis* (Bouby et al., 2013; Martín-Gómez et al., 2020; Orrù et al., 2015; Rivera et al., 2007; Terral et al., 2010; This et al., 2006). Thus, fully developed grape seed morphology and anatomy are considered a persistent varietal feature and therefore underlie the identification of varieties that are generally differentiated into two categories (Ristic and Iland, 2005): "Seeded" varieties are those that develop into normal viable seeds, and they are distinguished by their fertilized ovules. In contrast, due to the stenospermocarpy or parthenocarpy, "seedless" varieties do not produce normal seeds.

To promote local Moroccan grape varieties and contribute to the conservation of viticultural agrodiversity in Morocco, this study aims to characterize and highlight the phenotypic diversity of seed characteristics in twenty-seven *V. vinifera* grape varieties, as determined by different linear morphometric parameters. Morphometric data derived from seed shape and form can support traceability and authenticity assessments of traditional grapevine varieties by providing an objective and reproducible phenotypic fingerprint for each variety. Moreover, these results constitute a complementary tool for varietal identification, especially in the case of the traditional varieties studied in this work, which represent a rare and endangered heritage. Accordingly, the outcomes of this work provide a structured framework for the geometric characterization of seed morphology, establishing a quantitative basis for describing shape and form variability both within and among grapevine varieties. In addition, reference morphometric databases of traditional varieties facilitate comparisons with archaeological grape seeds, enabling the identification of ancient cultivated forms, the reconstruction of domestication pathways, and the assessment of historical biodiversity and crop dissemination patterns. Finally, the integration of morphometric data with molecular markers and classical ampelography can enhance varietal discrimination and overcome synonymy among closely related varieties.

MATERIALS AND METHODS

Linear morphometry for evaluating grapevine variety diversity

As part of the evaluation of the diversity of grapevine varieties, linear morphometry was performed, which is a traditional approach to morphometry (Bouby et al., 2018), involving measuring distances between points that are considered form- and shape-indicative. Height, length, width, and diameter are all subsumed within the linear morphometry. These parameters are initial, inexpensive, easy to collect, understand, and interpret, usually adequate for a biological characterization, and have been part of the biological toolbox since the toolbox itself existed. By comparing seed images, these statistics provide an accurate and quantitative description that enables the comparison of different or identical genotypes under varied conditions (Cervantes et al., 2019; Christodoulou et al., 2020).

Plant material

The samples were collected from fourteen sites belonging to two regions distinguished by the presence of traditional vineyards, which have been cultivated for an extended period (Figure 1). The fruit was sampled from August to September 2022. Therefore, the samples were taken from traditional vineyards at the harvest stage. We gathered samples of recognized fruits from every grapevine variety from each site, with the assistance of the farmers. Local varieties are understood to mean units defined and managed by farmers in a specific geographical area (Sadiki et al., 2002; Soriano Niebla, 2004). Indeed, farmers claim to be able to distinguish these units based on qualitative criteria of appreciation and specific designations, which are generally of limited value.

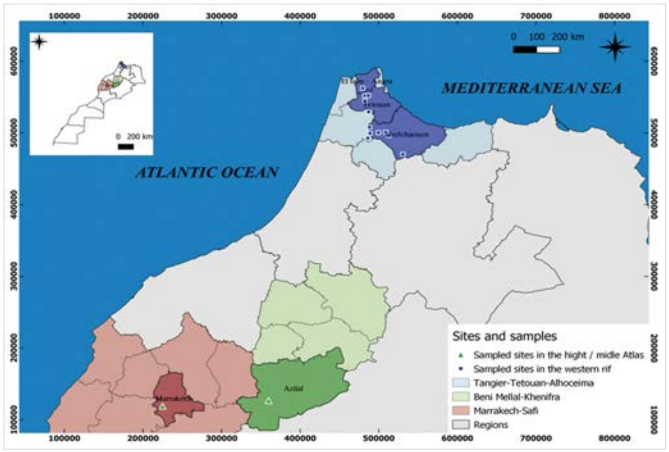


Figure 1. Origin of the samples from sites across Morocco

The study involved a seed collection of 27 indigenous Moroccan grapevine varieties of *V. vinifera*. Our collection originates from two distinct regions: Western Rif grapevine varieties are from the Tangier-Tetouan-Al Hoceima region, while the Middle and High Atlas varieties are from the Beni Mellal-Khenifra and Marrakech-Safi regions, respectively (Table 1).

Table 1. Plant material of twenty-seven traditional grapevine varieties studied and their origin

N°	Variety	Abbreviation	Origin
01	*El houmrani*	HR	Western Rif
02	*Lechhab*	LC	Western Rif
03	*Baydi*	AB	Western Rif
04	*El fassi*	FS	Western Rif
05	*Bezoul elaouda*	BA	Western Rif
06	*Taferyalet lbyed*	TB	Western Rif
07	*Hmer bouamer*	HB	Western Rif
08	*Boukhenzir*	BZ	Western Rif
09	*Babour hmara*	BH	Western Rif
10	*Taferyalet khal*	TK	Western Rif
11	*Eddibani*	ED	Western Rif
12	*El faqqas*	FK	Western Rif
13	*Taferyalet lesfer*	TS	Western Rif
14	*Matecha*	MT	Western Rif
15	*Valensi*	VL	Western Rif
16	*Sbeiaa lbnat*	SB	Western Rif
17	*Jeniani*	JN	Western Rif
18	*Chouikhi*	CH	Western Rif
19	*Douak*	DK	Western Rif
20	*Bouchouka*	BC	Western Rif
21	*Abouhou*	AH	Middle and High Atlas
22	*Tklit tmili*	TT	Middle and High Atlas
23	*Aguiar*	GY	Middle and High Atlas
24	*Laadari*	LD	Middle and High Atlas
25	*Tiniwen*	TW	Middle and High Atlas
26	*Aabou*	AA	Middle and High Atlas
27	*Laadari Marrakechi*	LR	Middle and High Atlas

Seed sample and measurement

In the level of each sampling site, depending on plant availability, two to three healthy and fully mature grapevines per variety were selected. To capture varietal variability, three to seven bunches were harvested from different positions on each vine at full ripeness. Seeds were manually extracted, cleaned, and air-dried under laboratory conditions. For morphometric analysis, twenty seeds per variety were randomly selected from the pooled seed lot and analyzed using image-based methods. The analysis of twenty seeds per variety was considered sufficient to characterize seed shape and form variability while limiting potential redundancy among highly similar samples. This sample size has been widely adopted in grape seed morphometric studies and allows reliable multivariate and variance analyses without over-representation of individual vines or bunches (Cervantes et al., 2021; Rivera et al., 2007). In this framework, a total of 540 seeds were scanned and subjected to digital image analysis to capture all the variability in the Moroccan local grapevine varieties, with some seed populations sampled derived from cultivars that have been previously described in the European *Vitis* Database available at http://www.eu-vitis.de/index.php. Eleven characters of the linear morphometry were measured corresponding to the significant parts of the seed (Rivera et al., 2007) (Table 2, Figure 2). Certain parameters used for the morphological characterization of seeds are also outlined in OIV descriptors 242–244 (OIV, 2023). To contrast the morphology of the Moroccan local grapevine seeds. Length and width are shape measurements. However, in combination, the ratio between the length and width of the same seed describes the form, indicating how the shape has evolved (Bollard, 1970).

Parameters (EPS, LBH, and EBB) were measured using a digital caliper (Mitutoyo, CD-15APX, Japan, accuracy ± 0.01 mm) (Barbagallo et al., 2021). Additionally, optical digital images were captured using a Canon IJ Scan desktop scanner (Canon CanoScan LiDE 120) set to 300 dpi to scan the seeds. LoG, LaG, LBB, LBD, LBV, LoCH,

LaCH, DCHS, Circ, RoNd, and SoLd were measured using ImageJ (v. 1.53e) an image analysis program (Rasband, 2018). We acquired images of the seeds from a variety of blue-shade backgrounds, allowing us to select the optimal images for measurement (Loddo et al., 2021).

Table 2. Morphometric parameters used for the characterization of grapevine seeds

N°	Parameters	Abbreviation
01	Total length of seed	LoG
02	Seed width	LaG
03	Seed thickness	EPS
04	Breadth of the beak at the hilum	LBH
05	Breadth of the beak at the seed base	LBB
06	Beak length in dorsal view	LBD
07	Beak length in ventral view	LBV
08	Thickness of the beak at the seed base	EBB
09	Total length of chalaza scutellum	LoCH
10	Maximum breadth (diameter) of the chalaza scutellum	LaCH
11	Distance from the chalaza apex to the apex of the seed	DCHS
12	Aspect ratio	LI
13	Circularity	Circ
14	Roundness	RoNd
15	Solidity	SoLd

Throughout this study, the aspect ratio, the circularity, the roundness, and the solidity are considered as shape descriptors. Aspect ratio is the ratio of length/width (Cervantes et al. 2021). Moreover, circularity (1), roundness (2), and solidity (3) were calculated as described by Zdilla et al. (2016).

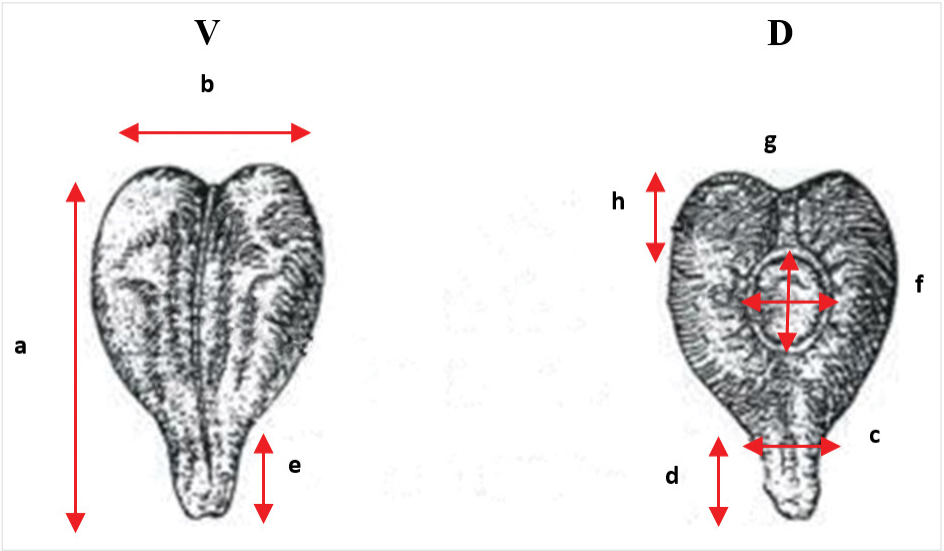


Figure 2. Figure of a grape seed, showing the measurements realized with image J for the dorsal face (D) and ventral face (V): **a**. Total length of seed, **b**. Seed width, **c**. Breadth of the beak at the seed base, **d**. Beak length in dorsal view, **e**. Beak length in ventral view, **f**. Total length of chalaza scutellum, **g**. Maximum breadth (diameter) of the chalaza scutellum and **h**. Distance from the chalaza apex to the apex of the seed.

Aspect ratio is also calculated for each seed (adapted from Ristic and Iland, 2005).

$$\text{Circularity} = 4\pi \times [\text{Area} / \text{Perimeter}^2] \quad (1)$$

$$\text{Roundness} = 4 \times [\text{Area} / (\pi \times \text{LoG}^2)] \quad (2)$$

$$\text{Solidity} = \text{Area} / \text{Convex Area} \quad (3)$$

Statistical analysis

The data was processed with R software v. 4.4.1 (R Core Team 2024). To show general trends in grapevine seed traits, descriptive analyses (mean and standard deviation) were used. Following Sokal and Braumann (1980), the coefficient of variation was calculated to estimate the variability of the parameters. A one-way ANOVA was performed to evaluate individual seed traits in the studied varieties. Then, a two-way ANOVA was performed to estimate the differentiation of grapevine varieties and geographical zones in individual seed traits. In instances where the analysis of variance (ANOVA) indicated a main effect that was found to be significantly different ($P < 0.05$). Using R packages "*multicomp*" and "*agricolae*" (Hothorn et al., 2008; Mendiburu and Yaseen, 2020), a comparison of mean values was conducted using Tukey HSD post hoc tests with a significance level of $P = 0.05$. Finally, using the *FactoMiner* R package (Lê et al., 2008), principal component analysis (PCA) was performed for inter-varietal comparisons of parameter values.

RESULTS

The analysis of variance and means comparison

Variability in seed morphometric parameters depending on varieties

The analysis of variance's results (ANOVA) for different morphometric traits studied for Middle and High Atlas varieties and Western Rif varieties disclosed a very significant difference ($P < 0,001$) between the different grapevine varieties studied. Notably, the parameters exhibited high F-values (Table 3).

The seven highest recorded F-values for Western Rif varieties compared to Middle and High Atlas varieties are related to the following parameters: LaCH, LoCH, DCHS, LoG, LBD, LBV, and LBH. Although the remaining parameters, EPS, RoNd, Ll, LaG, LBB, and EBB showed higher F-values for Middle and High Atlas varieties.

In the Western Rif varieties, LaCH showed the highest F-values (65.365); with *Lechhab* showing the widest chalaza (0.122 cm), however, *Douak* revealed the narrowest chalaza (0.043 cm). As well as for the Middle and High Atlas varieties, this parameter showed an F-value of (28.123). Moreover, the seeds with the widest chalaza (0.064 cm) belonged to *Abouhou*, while the *Laadari* showed the lowest average value (0.043 cm).

Regarding LoCH, the F-value showed for Western Rif varieties was (48.113), with the longest chalaza scutellum (0.141 cm) in *Baydi*, and the shortest ones (0.056) in *Douak*. For the Middle and High Atlas varieties (9.968), *Abouhou* recorded the longest chalaza (0.068cm), while *Aguiar* showed the shortest chalaza (0.055 cm).

Concerning DCHS, the analysis has shown an F-value of (41.835) for Western Rif varieties, with the highest mean value (0.148 cm) revealed by *Douak*, and the lowest value (0.061 cm) was shown in *Taferyalet khal*. About the Middle and High Atlas varieties, the F-value was (11.905). The upper mean value (0.186 cm) was recorded by *Laadari Marrakechi*, although the lowest average (0.126 cm) was shown by *Tiniwen*.

Evoking LoG and F-value of (40.707) were recorded for Western Rif varieties. The highest value (0.727 cm) was observed in the *Sbeiaa Ibnat*, while the lowest (0.522 cm) was noted in the *Douak*. Nevertheless, the F-value showed in the Middle and High Atlas varieties was (26.567), with the longest seeds presented (0.693 cm) by *Laadari*, and the shortest ones (0.582 cm) by *Tiniwen*.

In terms of Western Rif varieties, in LBV, an F-value (28.443) showed, the upper value (0.251 cm) was represented by *Sbeiaa Ibnat*, while *Taferyalet lesfer* had the lowest value (0.140 cm). Similarly, for LBD with an F-value of (27.871), *Sbeiaa Ibnat* had the longest beak on the dorsal face with an average value of (0.251 cm); however, the shortest beak on the dorsal face (0.141 cm) was recorded in *Taferyalet lesfer*.

Table 3. One-way ANOVA analysis and means comparison for each measured seed parameter (HSD post hoc tests)

Variable	Origin	Mean	CV(%)	F value	Pr (>F)	Tukey %
LoG	Middle and High Atlas	0.639 ± 0.049	7.730	26.578	0.000***	86%
	Western Rif	0.604 ± 0.056	9.359	40.707	0.000***	70%
LaG	Middle and High Atlas	0.368 ± 0.028	7.675	28.520	0.000***	86%
	Western Rif	0.346 ± 0.034	9.900	20.083	0.000***	55%
EPS	Middle and High Atlas	0.323 ± 0.027	8.505	46.009	0.000***	43%
	Western Rif	0.292 ± 0.026	9.209	16.752	0.000***	55%
LBH	Middle and High Atlas	0.069 ± 0.016	23.55	11.816	0.000***	57 %
	Western Rif	0.075 ± 0.018	24,971	12.585	0.000***	40%
LBB	Middle and High Atlas	0.183 ± 0.024	13.457	27.787	0.000***	71%
	Western Rif	0.177 ± 0.026	15.002	17.384	0.000***	65%
LBD	Middle and High Atlas	0.185 ± 0.030	16.196	18.240	0.000***	71%
	Western Rif	0.186 ± 0.036	19.488	27.872	0.000***	85%
LBV	Middle and High Atlas	0.184 ± 0.029	16.098	19.312	0.000***	71%
	Western Rif	0.186 ± 0.036	19.321	28.444	0.000***	80%
EBB	Middle and High Atlas	0.180 ± 0.023	13.184	24.212	0.000***	86%
	Western Rif	0.168 ± 0.022	13.117	18.963	0.000***	70%
LoCH	Middle and High Atlas	0.059 ± 0.006	11.647	9.968	0.000***	57%
	Western Rif	0.101 ± 0.024	24.085	48.113	0.000***	80%
LaCH	Middle and High Atlas	0.054 ± 0.009	16.924	28.123	0.000***	100%
	Western Rif	0.079 ± 0.020	25.942	65.365	0.000***	50%
DCHS	Middle and High Atlas	0.158 ± 0.027	17.637	11.905	0.000***	43%
	Western Rif	0.103 ± 0.035	33.965	41.836	0.000***	65%
LI	Middle and High Atlas	1.742 ± 0.170	9.761	33.101	0.000***	71%
	Western Rif	1.751 ± 0.176	10.050	18.561	0.000***	40%
Circ	Middle and High Atlas	0.659 ± 0.077	11.599	7.794	0.000***	71%
	Western Rif	0.632 ± 0.079	12.643	5.278	0.000***	35%
RoNd	Middle and High Atlas	0.572 ± 0.056	9.725	32.831	0.000***	86%
	Western Rif	0.560 ± 0.054	9.722	13.680	0.000***	55%
SoLd	Middle and High Atlas	0.945 ± 0.015	1.637	9.871	0.000***	86%
	Western Rif	0.936 ± 0.018	1.946	9.172	0.000***	50%

***: highly significant $P < 0.001$

On the other hand, for Middle and High Atlas varieties, (19.311) was the F-value registered for LBV; the longest beak in ventral view was shown (0.227 cm) for *Tklit tmili*, and the shortest one (0.165 cm) was recorded by *Aabou*. The same thing was noticed for LBD with an F-value of (18.240. *Tklit tmili* had the longest beak on the dorsal face (0.227 cm), whereas *Aabou* had the shortest (0.167 cm).

For LaG, which showed an F-value of (20.083) for the Western Rif varieties, the widest seeds (0.384 cm) belong to *Taferyalet lesfer*, while the narrowest seeds (0.305 cm) belong to *Douak*. Although the F-value that has been presented in Middle and High Atlas was (28.520); *Abouhou* was the variety with the widest seeds (0.404 cm), contrary to *Tiniwen*, which revealed the narrowest seeds (0.333 cm).

Furthermore, for Western Rif varieties, EBB had an F-value of (18.963), the mean comparison showed that the highest average (0.192 cm) was noticed in *El fassi* and the lowest average (0.135 cm) was noted in *Douak*. While for Middle and High Atlas, the F-value showed was (24.212), with the highest mean (0.205 cm) registered by *Aabou* and the lowest mean (0.157 cm) recorded by *Aguiar*.

Regarding LI, which indicates shape, for Western Rif varieties an F value of (18.561) was noted. *Sbeiaa Ibnat* had the biggest seeds (2.081), and *Taferyalet lesfer* had the smallest seeds (1.557). While for Middle and High Atlas varieties an F-value of (33.101) was shown, *Laadari* is distinguished by the highest mean value (1.940), even though the lowest value (1.585) has been found in *Aabou*.

Whereas, for LBB, the F-value was (17.384) for Western Rif grapevine varieties, we noted that *Sbeiaa Ibnat* recorded the highest value (0.213 cm), however, *Douak* registered the lowest one (0.147 cm). On the other hand, the F-value for the Middle and High Atlas varieties is noted (27.787). *Aabou* showed the highest value (0.212 cm), while the narrowest beak (0.154 cm) was observed in *Tiniwen*.

In the Western Rif varieties, EPS showed an F-value of (16.759), with the highest value for *Jeniani* (0.326 cm), and the lowest value (0.259 cm) for *Boukhenzir*. As well as for the Middle and High Atlas varieties, this parameter showed the highest F-value (46.009), *Abouhou* revealed the highest mean (0.363 cm), while *Aguiar* showed the lowest value (0.295 cm).

It is shown in the Western Rif varieties that RoNd revealed an F-value of (13.680) with the highest mean (0.618) noted in *Taferyalet lesfer* and the lowest mean (0.463) noted in *Bouchouka*. Moreover, for the Middle and High Atlas, the F-value was (32.831), with the highest mean (0.634) registered by *Abouhou*, and the lowest mean (0.504) recorded by *Laadari*.

The F-value for LBH was (12.585) for Western Rif varieties, with the highest mean value (0.114 cm) recorded by *El houmrani* and the lowest one (0.061) was shown by *El faqqas*. Evoking the Middle and High Atlas varieties, the F-value recorded was (11.816). *Laadari Marrakechi* showed the widest beaks at the hilum (0.079 cm), whereas *Tiniwen* recorded the lowest average value (0.050 cm) among the other varieties.

It can also be noticed that in Western Rif varieties, SoLd had an F-value of (9.172), the mean comparison showed that the highest average (0.954) is noticed in *Taferyalet lesfer*, and the lowest average (0.915) is noted in *El faqqas*. Likewise, for the Middle and High Atlas varieties, this parameter showed an F-value of (9.871. *Aabou* revealed the highest mean (0.957), while *Laadari* showed the lowest value (0.934).

Relating to Circ, an F-value was noticed (5.278) for Western Rif varieties, with the highest mean value (0.706) recorded by *Matecha*, and the lowest one (0.570) was shown by *Douak*. While for Middle and High Atlas varieties, (7.794) was the F-value registered for Circ; *Aabou* showed the highest mean value (0.729), even though the lowest value (0.615) was recorded by *Aguiar*.

To identify groups that differ from each other for different parameters studied, the Tukey test has been used.

As the number of grape varieties differs between the Western Rif and the Middle and the High Atlas, we have converted the number of groups into percentages. This allowed us to deduce that seven parameters showed high variability for Atlas varieties compared to Rif varieties: LaCH, LoG, LaG, EBB, RoNd, SoLd, LBB, Ll, Circ, and LBH. Just five parameters recorded high variability in Western Rif varieties compared to Atlas varieties: EPS, LBD, LBV, LoCH, and DCHS.

The means comparison realized by the test of Tukey at $P \leq 0,05$ (Table 3), showed that LaCH revealed the highest variability for Middle and High Atlas varieties at 100%; however, it showed only 50% of the variability in Western Rif varieties.

Followed by LoG, LaG, EBB, RoNd, and SoLd, which showed 86% variability in Middle and High Atlas varieties, while for Western Rif varieties, LoG and EBB revealed 70% of variability, LaG and RoNd recorded 55%, although SoLd noted 50%.

The parameters LBB, LBD, LBV, Ll, and Circ revealed 71% of the variability in Middle and High Atlas varieties. On the other hand, LBD showed 85% of variability in Western Rif varieties, followed by LBV with 80% of variability, then we have LBB, which recorded 65% of variability, followed by Ll with 40% of the variability, and ultimately, we find Circ with 35% of the variability.

Moreover, we have 57% of the variability observed in Middle and High Atlas varieties recorded by LBH and the LoCH, whereas the latter showed 80% of the variability in Western Rif varieties, while LBH only showed 40% of the variability.

Furthermore, EPS and DCHS revealed 43% of the variability of Middle and High Atlas varieties, while for Western Rif varieties, the DCHS showed 65% of the variability, and EPS showed only 40% of the variability.

Intraspecific variation between and within grapevine varieties and their geographic origin

The results of the analysis of variance (Two-Way ANOVA) for the different morphometric parameters studied for Middle and High Atlas varieties and Western Rif varieties exposed a very highly significant difference ($P<0.0001$) among different grapevine varieties for all parameters accordingly to varieties, while regarding origin, the majority of parameters showed very highly significant differences, except for LBB and RoNd which revealed a highly significant difference. However, LBD, LBV, and Ll showed non-significant values, which is most obvious in the original F-value of each parameter studied (Table 4).

The means comparison realized by the test of Tukey at $P \leq 0,05$ supported the previous results; according to the origin factor of the grapevine varieties, the latter were divided into two groups according to their origins, except for LBD, LBV, and Ll, which did not divide the varieties (Table 4).

Depending on the variety factor, the comparison of the means has enabled LBD to group the varieties studied into 19 different groups. Followed by LoG, LaCH, and DCHS, which classified the varieties into 18 distinct groups. Regarding LBB and LoCH, the varieties were divided into 17 groups. Whereas, for LaG, LBV, EBB, Ll, and RoNd, we noted 16 different groups for each parameter. Moreover, 15 groups were identified regarding EPS. Furthermore, the varieties were divided into 13 groups based on SoLd, and into 11 groups depending on Circ. Finally, we noted that LBH grouped the varieties studied into 10 different groups.

Seed morphometric parameters and varieties' variations, and correlation

The determination was made based on the mean values of all morphometric parameters for 27 studied seeds, and the principal component analysis (PCA) was conducted. The coefficients presented (Table 5) revealed the relative contribution of each measured variable to a particular principal component (factor), whereas the percentage of total variance was employed to ascertain the extent to which the total component solutions explained the parameters studied. The analyses indicated that the first two factors contributed 59.14% of the total variance, adequately explaining the differences observed among the evaluated varieties.

Table 4. The analysis of variance (Two-Way ANOVA) and means comparison for each measured seed parameter

Variable	F value		Pr(>F)		Tukey	
	Origin	Variety	Origin	Variety	Origin	Variety
LoG	114.96	37.15	0.000***	0.000***	2	18
LaG	89.52	21.6	0.000***	0.000***	2	16
EPS	263.05	21.71	0.000***	0.000***	2	15
LBH	15.17	12.48	0.000***	0.000***	2	10
LBB	9.77	19.40	0.00188**	0.000***	2	17
LBD	0.13	25.80	0.713ns	0.000***	1	19
LBV	0.77	26.53	0.38ns	0.000***	1	16
EBB	56.84	20.26	0.000***	0.000***	2	16
LoCH	1240.88	46.87	0.000***	0.000***	2	17
LaCH	732,79	62.29	0.000***	0.000***	2	18
DCHS	694.99	33.14	0.000***	0.000***	2	18
LI	0.57	21.37	0.45ns	0.000***	1	16
Circ	16.26	5.83	0.000***	0.000***	2	11
RoNd	8.35	17.27	0.0040**	0.000***	2	16
SoLd	35.54	9.36	0.000***	0.000***	2	13

***: highly significant $P<0.001$, ** significant $P<0.01$, ns: not significant $P\geq0.05$.

Table 5. Total and accumulated variance for the morphometric parameters of twenty-seven grapevine seeds

	Axe 1	Axe 2	Axe 3
Variance	5.06	3.81	2.74
% of var.	33.76	25.38	18.29
Cumulative % of var.	33.76	59.14	77.43

The first principal component was responsible for 33.76% of the total variance, and a notable correlation has been identified between six parameters LoG (0.89), EPS (0.82), LBB (0.78), SoLd (0.72), DCHS (0.61) and EBB (0.59). The second factor is associated with 25.38% of the total variance, and it is positively and very highly correlated with LI (0.78), LBV (0.72) and LBD (0.69). However, RoNd (-0.87), Circ (-0.62) and LaG (-0.59) are significantly and negatively correlated to this factor. LBH (0.64), LoCH (0.78) and LaCH (0.78) are highly correlated to the third factor with 18.29% of total variance (Table 6).

The biplot of the initial two factors, which explained 59.14% of the cumulative variance, revealed that the varieties were clustered into three distinguished groups (Figure 3). The First group with the biggest seeds includes the following varieties (SB, BC, CH, FS, JN, LD, and TT). These are strongly and positively correlated to factor 1 for which is based on the parameters: LoG, EPS, LBB, EBB, DCHS, and SoLd. The second group comprises varieties with large, round, and circular seeds (LR, GY, TW, AA, AH, MT, HB, and TS).

Table 6. Factors for the morphometric parameters (measures) of twenty-seven grapevine seeds

	Dim.	Ctr	Dim.	Ctr	Dim.	Ctr
LoG	0.89	15.77	0.19	0.96	0.03	0.03
LaG	0.56	6.16	-0.59	9.09	0.37	5.07
EPS	0.82	13.22	-0.27	1.96	-0.13	0.61
LBH	0.08	0.12	0.24	1.53	0.64	14.79
LBB	0.78	11.92	0.04	0.04	0.34	4.32
LBD	0.62	7.53	0.69	12.72	-0.00	0.00
LBV	0.59	7.01	0.72	13.55	0.02	0.01
EBB	0.59	6.78	-0.02	0.01	0.53	10.35
LoCH	-0.30	1.83	0.36	3.36	0.78	21.88
LaCH	-0.39	3.13	0.25	1.69	0.78	22.19
DCHS	0.61	7.30	-0.44	5.13	-0.53	10.22
LI	0.39	3.09	0.78	16.04	-0.33	4.07
Circ	0.48	4.60	-0.62	10.17	0.34	4.21
RoNd	-0.26	1.39	-0.87	19.93	0.18	1.24
SoLd	0.72	10.16	-0.38	3.82	0.17	1.01

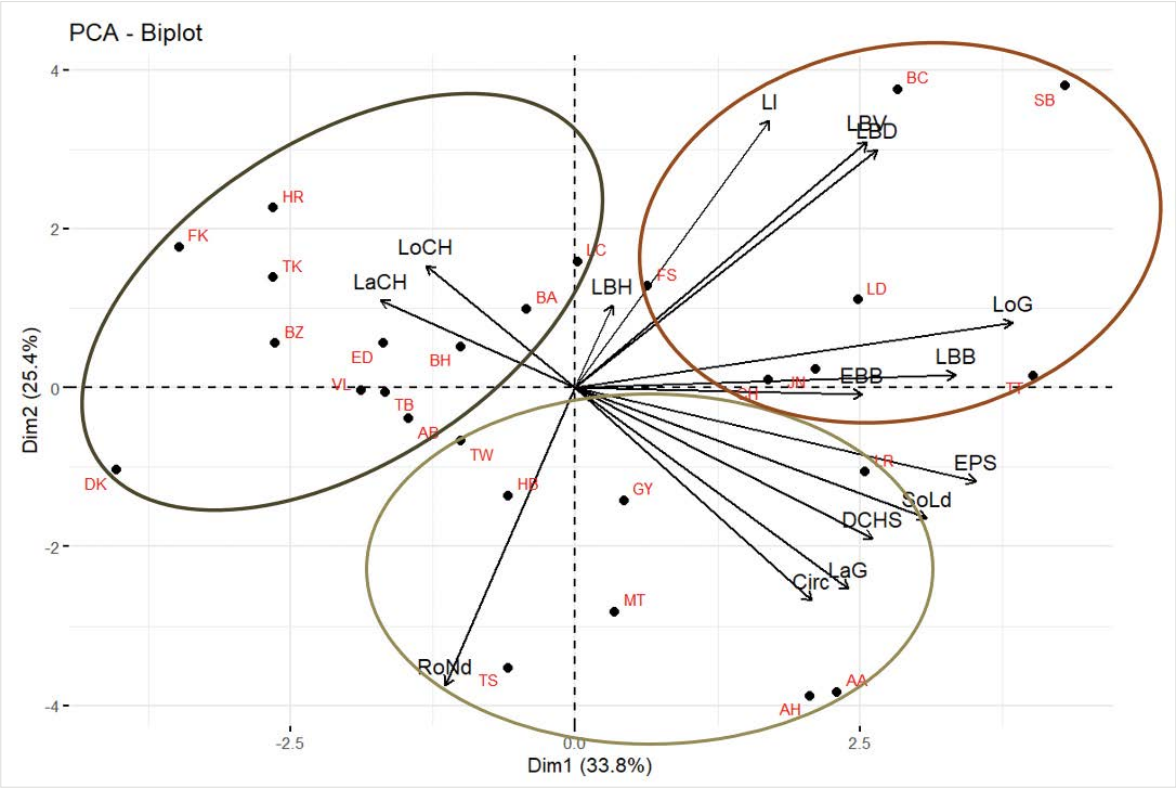


Figure 3. A biplot of Principal Component Analysis shows 61.58% of the variability of grapevine seed parameters

This group is highly and negatively correlated to Factor 2, which is based positively on LI and LBD, and LBV, and negatively on LaG, RoNd, and Circ. While the third cluster regroups all remaining varieties (LC, BH, BH, AB, TB, ED, VL, BZ, TK, HR, FK, and DK) have the smallest seeds since it's negatively correlated to Factor 1.

Remarkably, Western Rif varieties (AB, BA, BC, BH, BZ, CH, DK, ED, FK, FS, HB, HR, JN, LC, MT, SB, TB, TK, TS, and VL) have been dispersed throughout the biplot, which means they have different calibers. The biplot also features a gradient classification; all our grapevine varieties can be classified into three groups: big-seeded, round and circular-seeded, and small-seeded. The first group comprises five Western Rif varieties and two Atlas varieties with big seeds (SB, BC, CH, FS, JN, LD, and TT). Moreover, the second group with round and circular-seeded varieties (LR, GY, TW, AA, AH, MT, HB, and TS). It's noteworthy that this latter includes most Middle and High Atlas varieties and only three Western Rif varieties. However, the last one regroups only Western Rif varieties, which are small seeded (LC, BH, BH, AB, TB, ED, VL, BZ, TK, HR, FK, and DK).

DISCUSSION

At the end of the Western Mediterranean, specifically in Morocco, the natural climatic conditions are well adapted to the cultivation of the grapevine, olive tree, fig tree, and cereals. (El Oualkadi and Hajjaj, 2019). But many ecosystems' resistance will probably be surpassed, resulting in alterations to their structure and function under the ongoing rate of climate change (Peñuelas et al., 2018). Therefore, seed trait diversity reveals a sequence of strategies of crops designed to cope with environmental stress (Kassout et al., 2022). This study enabled us to identify seeds of local varieties in Morocco using different linear morphometric parameters. Through calculating the mean, the standard deviation, and the coefficient of variation, the description of the variability of Middle Atlas, High Atlas, and Western Rif grapevine varieties via quantitative seed parameters. *Sbeiaa lbnat* exhibited the longest seeds (0.727 cm), as well as the longest and widest beak (0.213 cm and 0.251 cm, respectively), resulting in the highest aspect ratio (2.081) among the studied varieties. These results suggest a close relationship between seed shape and berry morphology, as previously reported by Barbagallo et al. (2019). According to Hmimsa et al. (2021, 2023), *Sbeiaa lbnat* is characterized by a truncovoid berry shape, which in accordance with our findings. Similarly, the *Bouchouka* variety showed a long, elliptical berry shape along with elongated seeds (0.663 cm). Similar observations were reported for Turkish varieties such as Besirane, Mirani, and Savdani (Arslan et al., 2018), as well as for Palestinian varieties including Bairuti, Marawi-Haba-Tawela, and Marawi-Taweel (Rezq Basheer, 2015). Regarding the width and thickness of the seed, *Abouhou* exhibited the highest values for these two parameters. This relationship between seed width and thickness was also noted in the study of phenotypic characteristics of seeds of Sicilian grapevine varieties conducted by Barbagallo et al. (2019). As for the breadth of the beak at the hilum, *Elhoumrani* had the highest value, consistent with findings by Rivera et al. (2007) for the *Airén* and *Kadin Barmak* varieties. Regarding the thickness of the beak at the seed base, *Aabou* had the highest value. The *Baydi* variety was found to have the longest chalaza scutellum and the greatest breadth of the chalaza scutellum after the *Lechhab* variety. Additionally, *Laadari Marrakechi* showed the longest distance from the chalaza apex to the apex of the seed. However, *Douak's* berries are characterized by the smallest seeds in the collection, which is evident in the following parameters: total length of seed, seed width, breadth of the beak at the seed base, thickness of the beak at the seed base, total length of chalaza scutellum, and the maximum breadth (diameter) of the chalaza scutellum. Circularity and roundness expressed an inverse relationship to the aspect ratio; the latter showed the lowest value in *Taferyalet lesfer*, while this variety recorded the highest value for roundness. The same was observed for circularity in Middle and High Atlas varieties; *Aabou* recorded the highest average, but it had the lowest average of aspect ratio. This finding was also noted by Cervantes et al. (2021) and Di Cecco et al. (2024).

We can confirm a reciprocal relationship between seed shape and altitude and temperature. Based on the averages of the majority of morphometric parameters (LoG, LaG, EPS, LBB, EBB, DCHS, Circ, RoNd, and SoLd) (Table 3). To elaborate further, seeds are bigger, wider, and more circular and rounded in arid conditions (the Middle and High Atlas's grape seeds). These outcomes support the hypothesis that the shape of plants can be related to elevation; consequently, the development of seeds is restricted in high-elevation and low-temperature environments (Qi et al., 2014). The analysis of variance (Two-Way ANOVA) confirmed a very significant difference with high F-values for all varieties, which means that there is a high variability rate not only between varieties but also within the same variety (intra-varietal variability). Accounting for this intraspecific seed trait variation could significantly enhance the knowledge of how different plants respond to changes in their environment (Saatkamp et al., 2019). The same result was observed for the origin factor, except for the three parameters: the beak length in dorsal view, the beak length in ventral view, and the aspect ratio (LI), which seem to be non-significant when it comes to the environment factor. Therefore, they did show diversity within the varieties, but they did not distinguish the Western Rif varieties from the Middle and High Atlas varieties. The significant intra- and inter-varietal variability observed in this study can be explained by the fact that these traditional grapevine varieties belong to the group of landraces, which encompass primitive, farmer-maintained, traditional, local and folk varieties (Lazaridi et al., 2024). As reported by Marone et al. 2021, landraces exhibit a high level of diversity both between and within populations, reflecting their role as valuable reservoirs of genetic diversity. This diversity is continuously shaped by both natural and human selective pressures, thereby limiting genetic uniformity and resulting in a high degree of genetic heterogeneity within each landrace (Veteläinen et al., 2008). Traditional varieties possess strong adaptive capacities that have enabled farmers to cope with adverse environmental conditions and multiple biotic stressors (Ramesh et al., 2023). Consequently, these varieties contribute substantially to food security, primarily due to their rich genetic diversity. For these reasons, despite having been historically neglected and underutilized, traditional varieties are regaining scientific and agricultural interest in response to the growing risk of genetic erosion (Ramirez-Villegas et al., 2020; Khoury et al., 2022).

From principal component analysis (PCA) results based on our linear morphometry and shape parameters (Figure 3), our grape varieties are dispersed throughout the biplot, which leads us to conclude that there is a high diversity rate within our collection and distinct phenotypes. We can easily deduce that Western Rif grapevine varieties showed long, medium, and small seeds, although Middle and High Atlas grapevine varieties showed only Big or more round and circular seeds. This finding demonstrates that grape seeds from Western Rif varieties (humid conditions) have different phenotypes compared to those from the Middle and High Atlas (arid conditions). These results indicate that grapevine seed characteristics are largely determined by varietal identity, reflecting the genetic influence on seed morphology. Furthermore, the observed variation suggests that environmental factors, such as site-specific conditions, may also contribute to differences in seed traits, highlighting the combined effect of genotype and growing environment on seed phenotypic variability. As Kassout et al. (2022) have also shown for carob seeds. Moreover, the kernel size and shape can be influenced by both cultivar and growing environment, according to Mougiou et al. (2023).

CONCLUSION

Based on the phenotypic characteristics of grape seeds, the current study provides a description, characterization, and even classification of Moroccan local grapevine varieties. Seed morphology could therefore prove useful for studying the correlation between grape varieties and their intra- and inter-varietal variability, bearing in mind its limitations and coupling it with other morphological characters based on leaf, berry, and molecular characterization. Morphometric parameters reveal a significant diversity between grapevine varieties,

as well; they also allowed for differentiating between the individuals studied with apparent discrimination.

Concerning genetic resource conservation, this study affirms the importance of the agroecosystems of the Middle Atlas, the High Atlas, and the Western Rif, which constitute an agrodiversity refuge (Achtak et al., 2010; Aumeeruddy-Thomas and Hmimsa, 2018) of which; like other emblematic species of these areas (Hmimsa et al., 2024; Cao et al., 2024; Toujgani et al. 2022; 2024; Kassout et al., 2023; Ater el al., 2020); likewise, this work allowed us to achieve a fundamental step for the conservation of genetic resources to preserve this material, and especially to be able to meet the current and future expectations of users of plant genetic resources (geneticists, breeders, botanists, nurserymen, ...).

ACKNOWLEDGEMENTS

The authors thank the farmers of the various visited sites for their contribution to realizing this study and for fruit sampling, and El Haitor M., who tends the vines at the smart farm of the Polydisciplinary Faculty in Larache.

This study was supported by a scholarship from the National Centre of Scientific and Technical Research of Morocco (Grant n°: 8UAE2022).

REFERENCES

Abdel-Hameed, U., Khawla, A., Nahla, E. (2020) Genetic diversity of grapevine (*Vitis vinifera* L.) cultivars in Al-Madinah Al-Munawara based on molecular markers and morphological traits. Bangladesh journal of Plant Taxonomy, 27 (1), 113–127. DOI: https://doi.org/10.3329/bjpt.v27i1.47573

Achtak, H., Ater, M., Oukabli, A., Santoni, S., Kjellberg, F., Khadari, B. (2010) Traditional agroecosystems as conservatories and incubators of cultivated 19 plant varietal diversity: the case of fig (*Ficus Carica* L.) in Morocco. BMC Plant Biol, 10 (1), 28. DOI: https://doi.org/10.1186/1471-2229-10-28

Arslan, T., Doğan, A., Uyak, C. (2018) Ampelographic Identification of Grape Varieties Grown in Yüksekova (Hakkâri) Region. Journal of Agricultural Faculty of Gaziosmanpasa University, 35 (3), 217-226. DOI: https://doi.org/10.13002/jafag4469

Ater, M., El Fatehi, S., El Oualkadi, A., Hmimsa, Y. (2020) La cultura tradicional de la vid en la región norte de Marruecos: Existencia de posibles influencias andaluzas? In : Carabaza, J.M., Hernandez-Bermejo, J.E. (Eds), La vid en al Andalus : Tradicion, Diversidad y Patrimonio, pp. 279-294.

Aumeeruddy-Thomas, Y, Hmimsa, Y. (2018) Fig and olive domestication in the Rif, Northern Morocco. In: Stepanoff, C., Vigne, J.-D., eds. Hybrid Communities: Biosocial Approaches to Domestication and Other Transspecies Relationships. London: Routledge, pp. 179–198.

Barbagallo, MG., Patti, D., Pisciotta, A. (2019) Phenotypic traits of berries and seeds of Sicilian grape cultivars (*Vitis vinifera* L.). Scientia Horticulturae, 261 (5), 01-09. DOI: https://doi.org/10.1016/j.scienta.2019.109006

Bollard, EG. (1970) The physiology and nutrition of developing fruit. In: Hulme AC., Rhodes M.J., eds. The biochemistry of fruit and their products. London: Academic Press, pp. 387–425.

Bouby, L., Bonhomme, V., Ivorra, S., Pastor, T., Rovira, N., Tillier, M., Pagnoux, C., Terral, J.F. (2018) Back from burnout: are experimentally charred grapevine pipstoo distorted to be characterized using morphometrics? Archaeological and Anthropological Sciences, 10, 943–954. DOI: https://doi.org/10.1007/s12520-016-0425-x

Bouby, L., Figueiral, I., Bouchette, A., Rovira, N., Ivorra, S., Lacombe, T., Pastor, T., Picq, S., Marinval, P., Terral, J.F. (2013) Bioarchaeological Insights into the Process of Domestication of Grapevine (*Vitis vinifera* L.) during Roman Times in Southern France. PLOS One 8 (5), 01–13. DOI : https://doi.org/10.1371/journal.pone.0063195

Boursiquot, J.M., Audeguin, L., Charmont, S., Desperrier, J.M., Dufour, M.C., Jacquet, O., Lacombe, T., Leguay, M., Moulliet, C., Ollat, N., Schneider, C., Serreno, C. (2007) Catalogue des variétés et clones de vignes cultives en France (2th édition). France: Institut Français de la Vigne et du Vin 2.

Cao, L., Hmimsa, Y., El Fatehi, S., Buatois, B., Dubois, M.P., Le Moigne, M., Hossaert-McKey, M., Aumeeruddy-Thomas, Y., Bagnères, A.G., Proffit, M. (2023) Floral scent of the Mediterranean fig tree: significant inter-varietal difference but strong conservation of the signal responsible for pollinator attraction. Scientific Reports, 13 (1), 5642. DOI: http://doi.org/10.1038/s41598-023-32450-6.

Cervantes, E., Martín-Gómez, J.J., Espinosa-Roldán, F.E., Muñoz-Organero, G., Tocino, Á., Cabello-Sáenz de Santamaría, F. (2021) Seed Morphology in Key Spanish Grapevine Cultivars. Agronomy, 11 (4), 734. DOI: https://doi.org/10.3390/agronomy11040734.

Cervantes, E., Martín-Gómez, J.J. (2019) Seed shape description and quantification by comparison with geometric models. Horticulturae, 5 (3), 60. DOI: https://doi.org/10.3390/horticulturae5030060

Cervantes, E., Martín Gómez, J.J, Espinosa-Roldán, F., Muñoz-Organero, G., Tocino, Á., Santamaría, F. (2021) Seed apex curvature in key Spanish grapevine cultivars. Viticulture Data Journal, 3, 01-16. DOI: https://doi.org/10.3897/vdj.3.e66478

Cervantes, E., Martín-Gómez, J.J., Rodríguez-Lorenzo, J.L., del Pozo, D.G., Cabello Sáenz de Santamaría, F., Muñoz-Organero, G., Tocino, Á. (2025) Seed Morphology in *Vitis* Cultivars Related to Hebén. AgriEngineering, 7 (3), 62. DOI: https://doi.org/10.3390/agriengineering7030062

Christodoulou, M.D., Clark, J.Y., Culham, A. (2020) The Cinderella discipline: morphometrics and their use in botanical classification. Botanical Journal of the Linnean Society. 194 (4), 385–396. DOI: https://doi.org/10.1093/botlinnean/boaa055

Di Cecco, V., Manzi, A., Zulli, C., Di Musciano, M., D'Archivio, A.A., Di Santo, M., Palmerini, G., Di Martino, L. (2024) Study of Grapevine (*Vitis vinifera* L.) Seed Morphometry and Comparison with Archaeological Remains in Central Apennines. Seeds, 3 (3), 311-323. DOI: https://doi.org/10.3390/seeds3030023.

El Fatehi, S., Ater, M., Hmimsa, Y. (2021a) Ampelometric and Ampelographic Characterization of Leaves of Indigenous "*Vitis vinifera* ssp. *Vinifera*" in the North of Morocco. Journal of Biology and Life Science, 2 (1), 8. DOI: https://doi.org/10.3390/BDEE2021-09461.

El Fatehi, S., Hmimsa, Y., Ater, M. (2021b) Assessment of agromorphological diversity of chickling-vetch (*Lathyrus cicera* L.) landraces in the traditional agroecosystems of Morocco. Australian Journal of Crop Science, 15 (10), 1289-1297. DOI: http://doi10.21475/ajcs.21.15.10.

El Oualkadi, A., Hajjaj, B. (2019) Characterization of grape berries of same local varieties in Morocco. International Journal of Environment Agriculture and Biotechnology, 4 (6), 1690-1694. DOI: https://dx.doi.org/10.22161/ijeab.46.9

Galet, P. (1990) Cépages et vignobles de France (2nd edition). Montpellier : Paul Déhan Press

Galet, P. (2015) Dictionnaire encyclopédique des cépages et de leurs synonymes (2nd edition). Paris, France: Féret.

Gardner, Z.E., Lueck, L., Erhardt, E.B., Craker, L.E. (2012) A morphometric analysis of *Actaea racemosa* L. (Ranunculaceae). Journal of Medicinally Active Plants, 1 (2), 47–59. DOI: https://doi.org/10.7275/R5M906KB

Gramaje, D., Úrbez-Torres, J., Sosnowski, M. (2018) Managing grapevine trunk diseases with respect to etiology and epidemiology: Current strategies and future prospects. Plant Disease, 102 (1), 12–39. DOI: https://doi.org/10.1094/PDIS-04-17-0512-FE

Hothorn, T., Bretz, F., Westfall, P. (2008) Simultaneous inference in general parametric models. Biometrical Journal, 50 (3), 346–363. DOI: https://doi.org/10.1002/bimj.200810425

Hmimsa, Y., Benziane, W., Moudni, Z., Ater, M., El Fatehi, S. (2021) Ampelographic and Ampelometric Characterization of Berries and Seeds from Traditional Vineyards in Morocco. Proceedings of The 1st International Electronic Conference on Biological Diversity, Ecology and Evolution, 15–31 March 2021, Biology and Life Sciences Forum, 2 (1), 7.

Hmimsa, Y., El Fatehi, S., Ater, M., Dihaz, N., Moudni, Z., Benziane, W., Sinkovič, L., Pipan, B., Meglič, V., Mužina, Š., Kapazoglou, A., Pitsoli, T., Ntanos, E., eds. (2023). MEDVITIS: diversity of Mediterranean *Vitis* spp. genetic resources. Morocco: Le Printer Press.

Hmimsa, Y., Ramet, A., Dubuisson, C., El Fatehi, S., Hossaert-McKey, M., Kahi, H., Munch, J., Proffit, M., Salpeteur, M., Aumeeruddy-Thomas, Y. (2024) Pollination of the Mediterranean Fig Tree, *Ficus Carica* L.: Caprification Practices and Social Networks of Exchange of Caprifigs among Jbala Farmers in Northern Morocco. Human Ecology, 52, 289–302. DOI: https://doi.org/10.1007/s10745-024-00493-6

JKI (2007) European *Vitis* Database. EU-Vitis. Available at: http://www.eu-vitis.de/index.php [Accessed 03 October 2025]

Kassout, J., Hmimsa, Y., El Fatehi, S., Ouahrani, A., Kadaoui, k., Chakkour, S., Ariza Mateos, D., Palacios Rodríguez, G., Navarro Cerrillo, R., Ater, M. (2022) Image analysis of Moroccan carob seeds (*Ceratonia siliqua* L.) revealed substantial intraspecific variations depending on climate and geographic origin. Ecological processes, 11 (34). DOI: https://doi.org/10.1186/s13717-022-00378-w

Kassout, J., Hmimsa, Y., Fatehi, S. E., Kadaoui, K., Houssni, M., Chakkour, S., Sahli, A., El Chami, M. A., Ariza-Mateos, D., Palacios-Rodríguez, G., Navarro-Cerrillo, R. M., Ater, M. (2023) Aridity Gradients Shape Intraspecific Variability of Morphological Traits in Native *Ceratonia siliqua* L. of Morocco. Plants, 12 (19), 3447. DOI: https://doi.org/10.3390/plants12193447

Khoury, C.K., Brush, S., Costich, D.E., Curry, H.A., de Haan, S., Engels, J.M.M., Guarino, L., Hoban, S., Mercer, K.L., Miller, A.J., Nabhan, G.P., Perales, H.R., Richards, C., Riggins, C., Thormann, I. (2022) Crop genetic erosion: understanding and responding to loss of crop diversity. New Phytologist, 233 (1), 84–118. DOI: https://doi.org/10.1111/nph.17733

Lazaridi, E., Kapazoglou, A., Gerakari, M., Kleftogianni, K., Passa, K., Sarri, E., Papasotiropoulos, V., Tani, E., Bebeli, P.J. (2024) Crop Landraces and Indigenous Varieties: A Valuable Source of Genes for Plant Breeding. Plants, 13 (6), 758. DOI: https://doi.org/10.3390/plants13060758

Lei, Q.Y., Bai, H.F., Zhang, W.H. (2009) Influence of diversity of prototypical ethnic culture in diversity of glutinous rice in southeast of Guizhou. Agricultural Science & Technology, 10 (5), 184–188.

Lê, S., Josse, J., Husson, F. (2008) FactoMineR: an R package for multivariate analysis. Journal of Statistical Software, 25 (1), 01–18. DOI: https://doi.org/10.18637/jss.v025.i01

Loddo, A., Di Ruberto, C., Vale, A.M.P.G., Ucchesu, M., Soares, J.M., Bacchetta, G. (2021) An effective and friendly tool for seed image analysis. The Visual Computer, 39, 335–352. DOI: https://doi.org/10.1007/s00371-021-02333-w

Ma, N., Yang, L., Min, Q., Bai, K., Li, W. (2022) The Significance of Traditional Culture for Agricultural Biodiversity—Experiences from GIAHS. Journal of Resources and Ecology, 12 (4), 453-461. DOI: https://doi.org/10.5814/j.issn.1674-764x.2021.04.003

Marone, D., Russo, M.A., Mores, A., Ficco, D.B.M., Laidò, G., Mastrangelo, A.M., Borrelli, G.M. (2021) Importance of Landraces in Cereal Breeding for Stress Tolerance. Plants, 10 (7), 01-21. DOI: https://doi.org/10.3390/plants10071267

Maroufpoor, S., Bozorg-Haddad, O., Maroufpoor, E., Gerbens-Leenes, P.W., Lo´ aiciga, H.A., Savic, D., Singh, V.P. (2021) Optimal virtual water flows for improved food security in water-scarce countries. Scientific Reports, 11, 01-18. DOI: https://doi.org/10.1038/s41598-021-00500-6

Martín-Gómez, J. J., Gutiérrez del Pozo, D., Ucchesu, M., Bacchetta, G., Cabello Sáenz de Santamaría, F., Tocino, Á., Cervantes, E. (2020) Seed Morphology in the Vitaceae Based on Geometric Models. Agronomy, 10 (5), 01-16. DOI: https://doi.org/10.3390/agronomy10050739

Mendiburu, F., Yaseen, M. (2020) Agricolae: statistical procedures for agricultural research. R package version 1.4.0. Available at: https://myaseen208.github.io/agricolae/ https://cran.r-project.org/package=agricolae

Milanesi, C., Costantini, L., Firmati, M., Antonucci, F., Faleri, C., Buracchi, A., Cresti, M. (2014) Geometric Morphometry and Archaeobotany: Characterisation of Grape Seeds (*Vitis vinifera* L.) by Analysis of Form. Open Access Library Journal, 1 (3), 01-06. DOI: http://dx.doi.org/10.4236/oalib.1100634

Min, Q., Zhang, K., Xu, X. (2011) Agricultural connotation and conservation measures of traditional Dong villages: A case study on Xiaohuang Village, Congaing County, Guizhou Province. Resources Science, 33 (6), 1038–1045.

Mougiou, N., Maletsika, P., Konstantinidis, A., Grigoriadou, K., Nanos, G., Argiriou, A. (2023) Morphological and Molecular Characterization of a New Self-Compatible Almond Variety. Agriculture, 13 (7), 1-16. DOI: https://doi.org/10.3390/agriculture13071362

Musayev, M., Akparov, Z. (2013) Centuries-Old Results of Cultivation and Diversity of Genetic Resources of Grapes in Azerbaijan. In: Poljuha, D., Sladonja, B, eds. The Mediterranean Genetic Code - Grapevine and Olive. Croatia, InTech, pp. 99-123.

OIV (2021) Annual assessment of the world vine and wine sector in 2021. International Organisation of Vine and Wine. Available at: OIV_Annual_Assessment_of_the_World_Vine_and_Wine_Sector_in_2021.pdf

OIV (2023) OIV Descriptor list of grape vine varieties and *Vitis* species". Dijon: International Organisation of Vine and Wine.

Orrù, M., Grillo, O., Venora, G., Bacchetta, G. (2015) Seed morpho-colorimetric analysis by computer vision: a helpful tool to identify grapevine (*Vitis vinifera* L.) cultivars. Australian Journal of Grape and Wine Research, 21 (3), 508–519. DOI: https://doi.org/10.1111/ajgw.12153

Peñuelasa, J., Sardansa, J., Filellaa, L., Estiartea, M., Llusiàa, J., Ogayaa, R., Carnicerb, J., Bartronsa, M., Rivas-Ubacha, A., Graua, O., Pegueroa, G., Margalefa, O., Pla-Rabésb, S., Stefanescua, C., Asensioa, D., Preecea, C., Liua, L., Vergera, A., Ricoa, L., Barbetaa, A., Achotegui-Castellsa, A., Gargallo-Garrigaa, A., Sperliche, D., Farré-Armengola, G., Fernández-Martíneza, M., Liua, D., Zhanga, C., Urbinaa, I., Caminoa, M., Vivesa, M., Nadal-Salac, D., Sabatéb, S., Graciab, C., Terradas, J. (2018) Assessment of the impacts of climate change on Mediterranean terrestrial ecosystems based on data from field experiments and long-term monitored field gradients in Catalonia. Environmental and Experimental Botany, 152, 49-59. DOI: http://dx.doi.org/10.1016/j.envexpbot.2017.05.012

Qi, W., Guo, S., Chen, X., Cornelissen, J.H.C., Bu, H., Du, G. (2014) Disentangling ecological, allometric and evolutionary determinants of the relationship between seed mass and elevation: insights from multiple analyses of 1355 angiosperm species on the eastern Tibetan Plateau. Oikos, 123 (1), 23–32. DOI: https://doi.org/10.1111/j.1600-0706.2013.00448.x

R Core Team, (2024) R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing.

Ramesh, P., Juturu, V.N., Yugandhar, P., Pedersen, S., Hemasundar, A., Yolcu, S., Chandra Obul Reddy, P., Chandra Mohan Reddy, C.V., Veerabramha Chari, P., Mohan, R., Chandra Sekhar, A. (2023) Molecular genetics and phenotypic assessment of foxtail millet (*Setaria italica* (L.) P. Beauv.) landraces revealed remarkable variability of morpho-physiological, yield, and yield-related traits. Frontiers in Genetics, 14, 01-17. DOI: https://doi.org/10.3389/fgene.2023.1052575

Rasband, W.S. (2018) Image J. U.S. National Institutes of Health. Bethesda, Maryland, USA. Available at: http://imagej.nih.gov/ij/

Rezq Basheer, S. (2015) Ampelographic characterization of white grapevine cultivars (*Vitis vinifera* L.) grown in Palestine. Palestine Technical University Research Journal, 3 (1), 01- 11. DOI: https://doi.org/10.53671/pturj.v3i1.34

Ristic, R., Iland, P.G. (2005) Relationships between seed and berry development of *Vitis vinifera* L. cv Shiraz: Developmental changes in seed morphology and phenolic composition. Australian Journal of Grape and Wine Research, 11 (1), 43–58. DOI: https://doi.org/10.1111/j.1755-0238.2005.tb00278.x

Rivera, D., Miralles, B., Obón, C., Carreno, E., Palazon, J.A. (2007). Multivariate analysis of *Vitis* subgenus *Vitis* seed morphology. *Vitis*, 46 (4), 158–167. DOI: https://doi.org/10.5073/vitis.2007.46.158-167

Sadiki, M., Birouk, A., Bouizgaren, A., Belqadi, L., Rh'rib, K., Taghouti, M., Kerfal, S., Labhilili, M., Bouhya, H., Douiden, R., Saidi, S., Jarvis, D. (2002) La diversité génétique in situ du blé dur, de l'orge, de la luzerne et de la fève : options de stratégie pour sa conservation. In: Birouk A., Sadiki, M., Nassif, F., Saidi, S., Mellas, H., Bammoun, A., Jarvis, D., eds. La conservation in situ de la biodiversité agricole : un défi pour une agriculture durable. IPGRI, pp. 37–117.

Saadaoui, E., Martín, J.J., Bouazizi, R., Chokri, B.R., Grira, M., Saad, A., Khouja, M.L., Cervantes, E. (2015) Phenotypic variability and seed yield of *Jatropha curcas* L. introduced to Tunisia. Acta Botanica Mexicana, 1 (110), 119–134. DOI: http://doi.org/10.21829/ABM110.2015.193

Saatkamp, A., Cochrane, A., Commander, L., Guja, L., Jimenez-Alfaro, B., Larson, J., Nicotra, A. (2019) A research agenda for seed-trait functional ecology. New Phytologist, 221 (4), 1764–1775. DOI: https://doi.org/10.1111/nph.15502

Sadras, V.O., Moran, M.A. (2013) Nonlinear effects of elevated temperature on grapevine phenology. Agricultural and Forest Meteorology, 173, 107–115. DOI: http://dx.doi.org/10.1016/j.agrformet.2012.10.003

Sokal, R.R., Braumann, C.A. (1980) Significance tests for coefficients of variation and variability profiles. Systematic Zoology, 29 (1), 50-66. DOI: https://doi.org/10.2307/2412626

Soriano Niebla, J.J. (2004) Hortelanos de la Sierra de Cádiz. Las variedades locales y el conocimiento campesino sobre el manejo de los recursos geneticos. Villamartín, Cádiz: Mancomunidad de Municipios de la Sierra de Cádiz et Red Andaluza de Semillas "Cultivando Biodiversidad".

Terral, J.F., Tabard, E., Bouby, L., Ivorra, S., Pastor, T., Figueiral, I., Picq, S., Chevance, J.B., Jung, C., Fabre, L., Tardy, C., Compan, M., Bacilieri, R., Lacombe, T., This, P. (2010) Evolution and history of grapevine (*Vitis vinifera*) under domestication: new morphometric perspectives to understand seed domestication syndrome and reveal origins of ancient European cultivars. Annals of Botany, 105 (3), 443–455. DOI: http://doi.org/10.1093/aob/mcp298

This, P., Lacombe, T., Thomas, M.R. (2006) Historical origins and genetic diversity of wine grapes. Trends in Genetics, 22 (9), 511–519. DOI: https://doi.org/10.1016/j.tig.2006.07.008

Toujgani, I., El Fatehi, S., Ater, M., Hmimsa, Y. (2022). Phenotypic polymorphism of leaves among the populations of Moroccan chestnut (*Castanea sativa* Mill.). Australian Journal of Crop Science, 16 (10), 1170-1176. DOI: https://doi.org/10.21475/ajcs.22.16.10.p3649.

Toujgani, I., El Fatehi, S., Ater, M., Hmimsa, Y. (2024) Variability of the Moroccan sweet chestnut (Castanea sativa Mill.): Contribution of the morphological parameters and qualitative descriptors of the nut. Journal of the Saudi Society of Agricultural Sciences, 23 (2), 192-201.

Veteläinen, M., Negri, V., Maxted, N. (2008) European Landraces: On-Farm Conservation, Management and Use. Rome, Italy: Bioversity International

Zdilla, M.J., Hatfield, S.A., McLean, K.A., Cyrus, L.M., Laslo, J.M., Lambert, H.W. (2016) Circularity, Solidity, Axes of a Best Fit Ellipse, Aspect Ratio, and Roundness of the Foramen Ovale: A Morphometric Analysis With Neurosurgical Considerations. Journal of Craniofacial Surgery, 7 (1), 222–228. DOI: https://doi.org/10.1097/SCS.0000000000002285