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Assessment of morphological variability of leaves and fruits of three natural populations of wild caper (*Capparis spinosa* L.) in western Algeria

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ABSTRACT *Capparis spinosa* L., family Capparidaceae, is a spontaneous plant of great economic, medicinal and ecological importance. This study focused on the estimation of morphological variability of three populations of the spiny caper from western Algeria by measuring morphological traits of leaves, fruits and seeds. Variance analysis showed that there were significant ($P<0.05$) difference (number of seeds per fruit) to highly significant ($P<0.001$) difference (the other morphological traits) between the three spontaneous caper natural populations with coefficients of variation ranging from 6.39% to 24.11%. There were no interpopulation differences for fruit width ($P>0.05$). The populations of Taghit (Bechar) and Sidi Belattar (Mostaganem) showed the best morphological traits. The population from Taghit had the best means for leaf length (35.62±3.47 mm), fruit width (35.62±3.47 mm), fruit weight (11.06±2.74 g), peduncle length (79.55±12.26 mm) and number of seeds per fruit (157±40.20). The population from Sidi Belattar was characterized by the highest leaf widths (39.24±3.89 mm), petiole lengths (11.309±2.02 mm), fruit lengths (42.433±4.15 mm), seed lengths (3.46±0.20 mm) and thousand seed weights (12.15±1.75 g). While the population from Mghila (Tiaret) had the lowest means for most morphological traits. Principal component analysis (PCA) showed a geographical separation between the studied populations with a polymorphism of 83.31%. The hierarchical classification using Ward's distance classified the populations into two clusters related to climatic and edaphic gradients.

KEY WORDS *Capparis spinosa*; fruits; leaves; morphological variability; principal component analysis; seeds.

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INTRODUCTION

Algeria has a very rich ecological and plant diversity due to its biogeographical position. There are more than 3000 species belonging to several plant families, 15% of which are endemic and rarely explored; either in phytochemistry or pharmacology (Daira et al., 2016). Among these species, we chose to work on the spiny caper which belongs to the genus *Capparis* Tourn. ex L. of the family Capparidaceae, closely related to the Brassicaceae. There are about 350 species in the genus *Capparis* (Al-Safadi, Elias 2011). In Algeria, *Capparis spinosa* L. covers large areas but in a sparse manner (Bensghir- Boukhari, Serridi, 2007).

The spiny caper is considered as a rare shrub species, which also has characteristics for different uses (Douieb, Benlemlih, 2010). It is a xerophyte that can survive in areas where the annual rainfall is less than 200 mm (Barbera, 1991). *Capparis spinosa* grows in arid and semi-arid climatic zones. It is a drought, salinity and calcareous resistant (Stefanucci et al., 2018). It has an efficient root system, associated with nitrogen-fixing bacteria, allowing it to grow in non-fertile soil (Chalak et al., 2007). It grows spontaneously in cracks and crevices of crows and in stone walls (Soyler, Khawar, 2007). It is considered as an excellent material for wind screens and stabilization of sandy soils (Wang et al., 2016). It is aforage, melliferous, and ornamental plant (Benseghir-Boukhari, Seridi 2007).

The caper is 30 to 100 cm long, its roots can measure 6 to 10 m in length. The leaves are 2 to 5 cm long and alternate. The flowers are 5 to 7 cm wide. The fruit bursts at maturity, releasing seeds in a light red flesh. The seeds are 3 to 4 mm wide and reniform (Tlili et al., 2011a).

The identification of genetic variability by certain morphological traits is the first essential step in the description of genetic resources (N'da et al., 2014). In Algeria, many studies have been carried out on caper; they have focused mainly on the biological activities of the plant extracts such as; the broncho-relaxing effect (Benzidane et al., 2013), antioxidant effect and polyphenol content (Arrar et al., 2013), anti-inflammatory and hepatoprotective effects (Aichour et al., 2018) and immuno-modulatory effects (Aichour et al., 2016). However, there is very little information on the morphological variability and genetic diversity of natural populations of *C. spinosa*. The objective of this work is to study the inter-population phenotypic variation through quantitative morphological markers (leaves, fruits and seeds) from three different natural provenances of spiny caper from western Algeria.

MATERIAL AND METHODS

Plant material and site simpling

Leaves and mature fruits of wild caper were collected in August 2018 from three areas (Fig. 1) of western Algeria (Taghith, Sidi Belattar and Mghila). Sampling is carried out on 30 individuals for each caper population that have been randomly

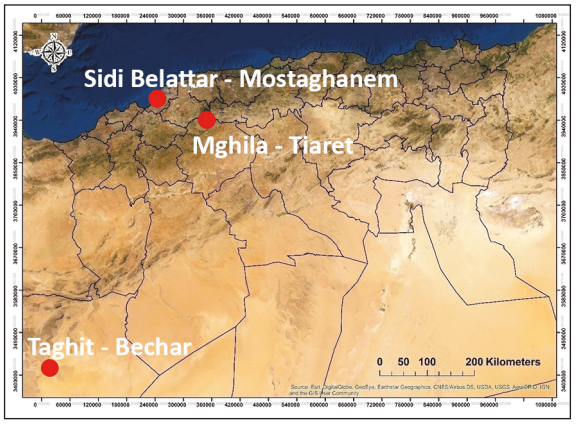

Figure 1. Localization of *Capparis spinosa* fruits and leaves sampling sites, in western Algeria.

selected and are spaced at least 10 m apart. The geographical coordinates as well as the climatic and soil characteristics of the three study areas are resumed in Table 1.

The study area is located between 30°48.833'N and 36°2.4338'N latitude and between 0°10.949'E and 2°0.682'0'E longitude (Table1). The region of Taghith (Bechar) is located in southwest Algeria at an altitude of 583 m and it is characterized by a Saharan climate with mild winters and low average annual rainfall and average maximum temperatures reaching 40 °C (Table 1). The region of Sidi Belattar (Mostaganem) is located in the northwest of Algeria, at an altitude of 34 m and characterized by a semi-arid climate with mild winters. The average rainfall in this region is moderate (Table 1). The region of Mghila (Tiaret) is located in the west of the country on the high plateaus. It is located at an altitude of 514 m and is characterized by a semi-arid climate with a cold winter. The average annual rainfall is moderate (Table 1).

Variations in soil characteristics are also observed in the three studied areas (Table 1). The soil pH is alkaline. It has a sandy-loam texture in the Taghith area and loamy texture in Sidi Belattar and Mghila. The analyzed soils are poor in organic matter with high limestone content in Sidi Belattar and Mghila.

Morphological analysis

The study of morphological polymorphism of leaves and fruits is based on 11 quantitative characteristics analyzed: Leaf length (LL), Leaf width

	Taghith	Sidi Belattar	Mghila
Altitude (m)	583	34	514
Latitude	30°48.833′N	36°2.4338′N	35°38.082′N
Longitude	2°0.682′0′E	0° 10.949′E	1°22.211′E
Precipitation (mm)	75.52	218.92	289.59
Average temperature (°C)	21.69	17.92	15.09
Maximal temperature (°C)	40.00	30.28	34.79
Minimal temperature (°C)	3.04	5.91	0.21
Emberger's rainfall-quotion (Q3)	8.60	47.4	36.4
Aridity index	2.38	7.78	11.50
Climate	Saharan mild	Semi-arid mild	Semi-arid cold
Water potential (pH)	8.36	8.20	8.56
Electricalc onductivity (µS/cm)	0.19	0.63	0.25
Total limestone (%)	4.67	54.00	58.50
Organic matter (%)	0.34	0.47	25.31
Sand (%)	87.26	31.67	25.31
Clay (%)	8.85	23.90	9.25
Loam (%)	3.89	44.43	65.44
Soil texture	Sandy loam	Loamy	Loamy

Table 1. Geographical and pedoclimatic characteristics of the different sampling sites.

(LWd); Petiole length (PtL); Fruit length (FL); Fruit width (FWd); Fruit weight (FWg); Peduncle length (PdL); Seed length (SL); Seed width (SWd); Thousand seed weight (TSWg) and Number of seed per fruit (NSF).

Length and width of leaves, fruits and seeds were measured with a digital caliper (BERENT BT4171 with 0.01 mm precision). Fruit mass and thousand seeds weightswere measured using an electronic balance (GIBERTINI E42S-B with 0.0001 g precision).

Statistical analysis

Statistical processing was carried out using SPSS (21) software for Windows; the analysis of variance was carried out by ANOVA. The comparison between homogeneous groups was performed by the Tukey test. Principal component analysis (PCA) was performed to establish correlations between climatic, soil and morphometric parameters with the three caper populations studied using XLSTAT software. Hierarchical ascending classification (HAC) in clusters was performed using Ward's distance.

RESULTS

Morphological parameters

The results of the analysis of variance for morphological traits, shown in Table 2, indicated that there were significant ($P<0.05$) differences between the three natural populations of caper for the number of seeds per fruit to highly significant ($P<0.001$) for the other morphological parameters except for fruit width where no significant differences were recorded between populations ($P>0.05$).

	Taghith	Sidi Belattar	Mghila	P	Cv %
LL ***	35.62±3.47^{c}	31.41±3.41^{b}	28.75±3.03^{a}	P<0.001	10.38
LWd ***	31.84±3.75^{a}	39.24±3.89^{b}	33.37±3.81^{a}	P<0.001	11.40
PtL ***	9.62±1.88^{a}	11.309±2.02^{b}	9.33±1.87^{a}	P<0.001	19.15
FL ***	35.41±6.63^{a}	42.433±4.15^{b}	41.94±4.72^{b}	P<0.001	13.25
FWd ns	20.29±2.32	18.514±8.51	18.431±1.79	P>0.05	22.36
FWg ***	11.06±2.74^{b}	8.7±1.64^{a}	8.567±2.25^{a}	P<0.001	23.32
PdL ***	79.55±12.26^{c}	62.94±10.66^{a}	70.09±7.70^{b}	P<0.001	14.45
SL ***	3.11±0.22^{a}	3.46±0.20^{b}	3.38±0.20^{a}	P<0.001	6.39
SWd ***	2.55±0.24^{a}	2.82±0.20^{b}	2.84±0.24^{b}	P<0.001	8.45
TSWg ***	10.04±2.30^{a}	12.15±1.75^{b}	9.41±1.11^{a}	P<0.001	16.41
NSF *	157±40.20^{b}	152±29.07^{b}	135±37.39^{a}	P<0.05	24.11

Table 2. Means of morphological parameters of *Capparis spinosa* (L.). Values represent the mean of 300 replicates ± standard deviation. Letters represent homogeneous groups according to a Tukey test when the trait was significantly different at the level of P < 0.05. *: Trait significantly different at the level of 5% (P<0.05); ***: Trait significantly different at the level of 0.1% (P<0.001); ns: no significant differences (P>0.05). Cv %: coefficient of variation.

Morphological characterization of the leaves (Table 2) indicates that the Taghith population had the longest leaves with an average of 35.62±3.47 mm; however, the minimum values for leaf length and petioles were recorded in the Mghila population. The population of Sidi Belattar was characterized by wider leaves and longer petioles with respective values of 39.24±3.89 and 11.30±2.02 mm.

The dimensions of the fruits varied between 35.41±6.63 and 42.433±4.15 mm in length and between 18.431±1.79 and 20.29±2.32 mm in width. The weight of the fruits varied between 8.567±2.25 and 11.06±2.74 g. The number of kernels per fruit ranged from 135±37.39 to 157±40.20 and the peduncle length varied from 62.94±10.66 to 79.55±12.26 mm. The values of seed length, seed width, and thousand kernel weights varied from 3.46±0.20 to 3.11±0.22 mm, from 2.55±0.24 to 2.84±0.24 mm and from 9.41±1.11 to 12.15±1.75 g, respectively (Table 2).

The population of Taghithwas characterized by the largest fruits with the longest peduncles and had the highest number of seeds per fruit and fruit weight. However, the population of Sidi Belattar was characterized by the longest fruits and the smallest peduncles. The fruits of the population of Mghila were characterized by the lowest values for fruit weight, fruit width and thousand seeds weight and number of seeds per fruit (Table 2).

Hierarchical ascending classification

The hierarchical classification using Ward's distance (Fig. 2) for the three populations of *C. spinosa* by measuring the distance between morphological characters, indicated the existence of two clusters; the first cluster grouped the two populations of caper from Sidi Belattar and Mghila, which are located in the north and have similar soil conditions (calcareous soil with a silty texture; a deficiency in organic matter, a salinity ratio in the soil). They also have similar climatic factors (rainfall, average temperatures and a semi-arid climate). The second cluster is represented by the population from Taghith which is characterized by a Saharan climate, with higher temperatures and low annual rainfall, also located at high altitudes. It also has a soil poor in organic matter, with a sandy texture and an alkaline pH.

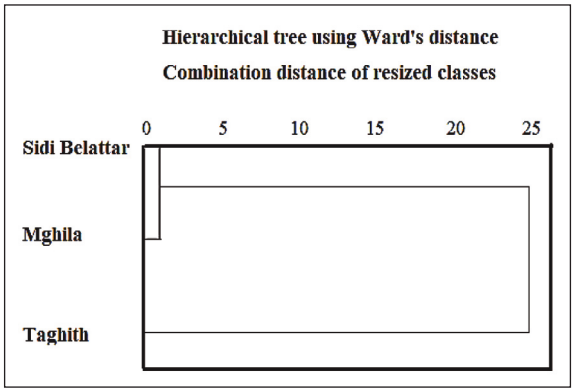

Figure 2. Dendrogram for hierarchical upward classification of morphological variables of different populations of *Capparis spinosa* fruits and leaves, based on Mahalanobis distances using the Ward clustering method.

Principal component analysis

A principal component analysis was performed on the measured morphological traits in order to study their relationship with the environmental variables of the populations studied.

The first two axes explained about 83.31% of the variation. The majority of the variables were well represented on the first axis with a percentage of 56.44% compared to the second axis that had a percentage of 26.87% in the separation and grouping of variables (Fig. 3).

The projection of the populations on the first axis brought out two groups (Fig. 3): one in the positive direction groups the two populations of Mghila and Sidi Belattar which were characterized by the closest average fruit and petiole lengths, leaf and seed widths and thousand seed weight. In the opposite direction was located the population of Taghith, Saharan region, which was characterized by the widest leaves and fruits and the highest peduncle lengths and number of grains per fruit.

Concerning the second axis (Fig. 3), the population of Mghila (Tiaret) appeared on the positive side, which was characterized by the smallest fruit lengths and peduncles; and in the opposite direction, the populations of Taghith and Sidi Belattar were grouped. The latter had the longest leaves and pe-

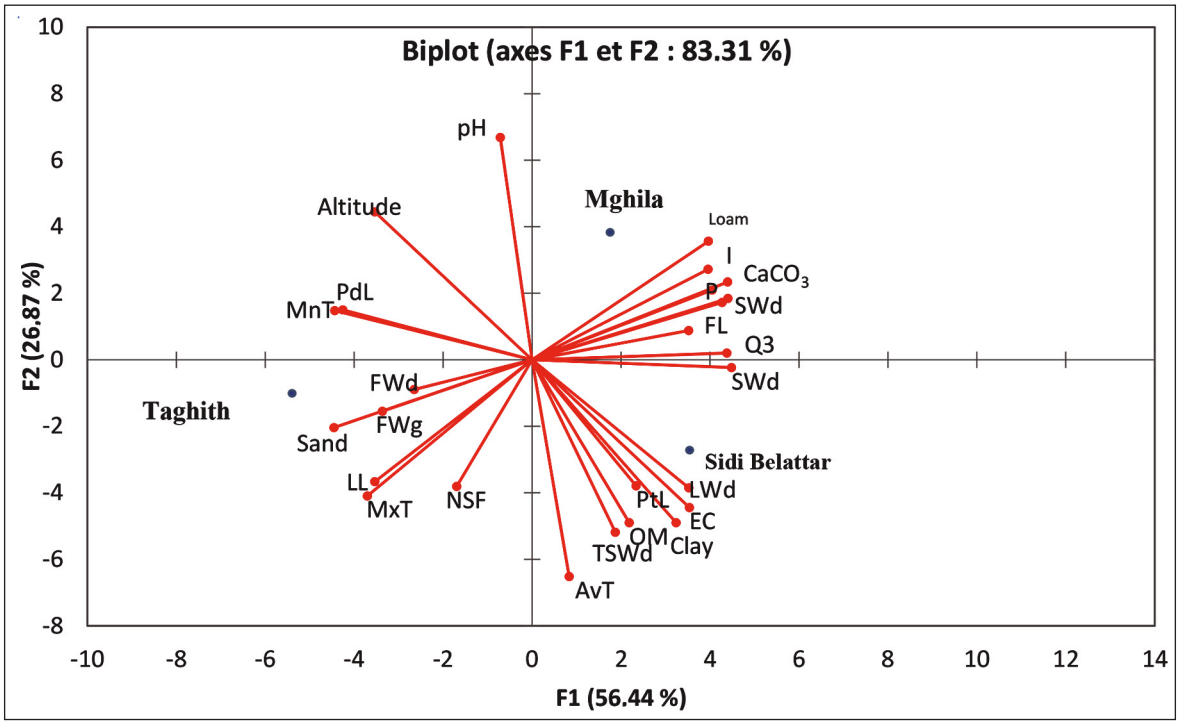

Figure 3. Principal component analysis developed on the measured morphological traits and their relationships with the environmental variables of the populations studied. CaCO3: total limestone; EC: electrical conductivity; I: aridity index; FL: leaf length; FWg: fruit weight; PdL: peduncle length; PtL: petiole length; LWd: Leaf width; FWd: Fruit width; SWd: Seed width; OM: Organic matter; NSF: Number of seeds per fruit; P: Annual precipitation (mm); TSWg: Thousand kernel weight; Q3: EMBERGER rainfall quotient; AvT: Average of annual temperature (°C); MxT: Average of maximal temperature (°C); MnT, Average of minimal temperature (°C).

tioles and the widest leaves and fruits, and the highest fruit weight and thousand grain weight and number of grains per fruit.

DISCUSSION

The three caper populations collected from western Algeria show significant differences in the measured morphological parameters. The results of the principal component analysis and the hierarchical classification by Ward's distance revealed the existence of two morphological groups within the populations studied which are distributed according to the bioclimatic gradient. The first group includes the populations of the semi-arid climate "Sidi Belattar and Mghila"; and the second includes the Taghith population of the arid climate.

Our results indicate a very large divergence between leaves, fruits and seeds of natural populations of caper from western Algeria. It is well known that in many species, morphological parameters are strongly influenced by genetic and environmental factors. Morphological variations can be presented as adaptation strategies of plants to different selection pressures (Rhimi et al., 2012). Saifi et al. (2011) indicate that rapid morphological changes in response to various ecological factors could mislead the perception of genetic differences among species.

The Taghith and Sidi Belattar populations are considered the best populations morphologically. The caper trees of Sidi Belattar were characterized by the longest and widest leaves and fruits and the highest fruit weights; however, the Taghith population had the longest leaves and widest fruits with the longest peduncles and the highest weight and number of seeds per fruit. This region is characterized by a Saharan climate with temperatures exceeding 40 °C and little rainfall. During the prospection on April, a shift in the phrenological cycle of the plant was observed; the caper plants of Taghith were found in the flowering-fruiting stage "premature capers", while in the regions of Mghila and Sidi Belattar, the caper plants were in the vegetative stage; this is probably due to the impact of the climate. Plants generally complete their life cycle and reach maturity when they accumulate their temperature requirements. A positive correlation was observed between temperature and caper productivity. Temperature is the main environmental factor affecting caper flowering, according to Sozzi & Vicente (2003).

The coefficients of variation ranged from 6.39% for seed length to 24.11% for number of seeds per fruit. Eco-geographical factors have, according to Ozbek & Kara (2013), a significant effect on the genetic diversity of *Capparis*. In concordance with other works that have been conducted on the morphological variability of caper, Saifi et al. (2010) show a very high level of polymorphism in natural populations of Moroccan caper. Also, studies on Tunisian ecotypes of *C. spinosa* by Tlili et al. (2011b) on 15 populations and by Rhimi et al. (2012) on 17 populations, revealed heterogeneity in this species. Saadaoui et al. (2013) and Bourhim et al. (2021) showed a very high diversity of *C. spinosa*. This diversity can be explained by various factors, such as phenotypic plasticity, geographical and ecological differentiation, topographical changes and the hybridization process. *Capparis spinosa* showed considerable morphological changes, this huge variability suggests that there is a complex structure within the wild forms of *C. spinosa* (Chedraoui et al., 2017).

The mean values of leaf length, leaf width and petiole length are comparable to the observations of El Amri et al. (2019) made on *C. spinosa* collected from two Moroccan regions with respective means of 30.81±1.215, 22.39±0.43 and 5.35±0.71 mm in Fez and 29.46±0.45, 20.63±0.35 and 4.497±0.505 mm in Safi. Bina & Bostani (2016) found averages of 24.8 mm for leaf length, 20.4 mm for leaf width and 6.5 mm for petiole length of southern Tehran capers. Gristina et al. (2014) recorded averages of 36.8 mm for leaf lengths and 6.9 mm for petiole length of subspecies *spinosa* and 39.51 mm for leaf lengths and 9.35 mm for petiole length of subspecies *rupestris*.

Furthermore, fruit dimensions (fruit length and width), fruit weight, peduncle length and number of seeds per fruit were comparable with those found in the work of Bina & Bostani (2016) who reported respective averages of 32.99 mm, 17.76 mm, 5.33 g, 7.51 cm, 232.84 seeds per fruit.

Morphological description of seeds is a required step for biodiversity analysis in natural populations as well as an important aspect for genetic, taxonomic and biodiversity studies (Saadaoui et al., 2013). The average lengths, widths and thousand-seed weights of caper were also comparable to the work of Tlili et al. (2011b) who recorded the averages of 3.45±0.30 mm for seed length, 2.86±0.27 mm for seed width and 10.14±2.46 g for thousand-

seed weigh. Also, Haciseferoğullari et al. (2011) found averages of 3.76±0.02 and 3.68±0.02 mm for seed length, 3.04±0.02 and 2.98±0.023 mm for seed width and 11.96±0.11 and 12.76±0.13g for *C. spinosa* and *C. ovata* respectively. Elamri et al. (2019) reported respective means for seed length and width in two Moroccan regions of 8.65±0.16 mm and 7.97±0.16 mm in Fez and 7.89±0.11 mm and 7.44±0.22 mm in Safi. Ozcan et al. (2004) also recorded averages of 10.34±0.159 mm and 9.21±0.141 mm for seed length and width. Akgül & Özcan (1999) found averages of 10.83 g for thousand seed weight for *C. spinosa* and 6.53 g for Capparis *ovata*. Ozbek & Kara (2013) reported that the seeds bear important taxonomic characters that could be used to differentiate the caper populations before further detailed analysis. In turn, Tlili et al. (2011) reported that seed weight is the most variable parameter, it was probably influenced by the environment of the parent plants and is also associated with internal variables affecting seed weight.

CONCLUSIONS

Morphological variability between populations of the natural caper in western Algeria is influenced by climatic and edaphic gradients and geographical distribution. The use of morphological traits for the study of the biodiversity of this species has allowed the effective identification of these studied populations of the Algerian thorny caper. It is therefore important to re-launch studies to identify other populations of the thorny caper in Algeria.

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