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RESEARCH ARTICLE

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Morphological and germination capacity of *Argania spinosa*'s (L) Skeels of Algeria South-West population: variability of fruit and stone morphotypes

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Abstract

Aim of study: The purpose of our study is the highlighting of phenotypic variability within the natural population of *Argania spinosa* (L.) Skeels by morphological characterization of fruits and stones and by evaluation germination capacity of stones.

Area of study: The Argan tree stand is located in southwest of Algeria (Tindouf).

Material and Methods: The fruits were collected on a sample of 30 mother trees for three consecutive years. We carried out the morpho-biometric characterization (shapes, dimensions and weight) of thirty fruits and thirty stones from each mother-tree, and assessed the germination capacity of the different morphotypes.

Main results: We found high variability of morphological characters of fruits and stones between trees. Five fruits shapes (oval, avoid, rounded, spherical and very spherical) and three different stones shapes (oval, avoid and spherical) were identified in mother-trees. The rounded, spherical and very spherical shapes of fruits are the most abundant (82%). High variability in the germination capacity of the different Argan tree genotypes and strong correlation were emphasised between capacity germination and stones shape and dimensions. Multivariate analysis showed that trees with small-sized, spherical stones showed better germination (98%) than trees with larger and elongated (oval) stones (51%). However, no significant difference was found between harvest years for any studied trait.

Research highlights: Results of this research allows the selection of mother- trees to improve the production of seedlings in nursery, to successful regeneration and to ensure conservation and sustainable use of the genetic resources of this rare and endangered species.

Additional keywords: *Argania spinosa*; variability; morphological; fruits; stones; germination capacity.

Authors´ contributions: Study design, collection and interpretation of data and drafting of the manuscript: SB. Statistical analysis: HH. Technical support: KMK and DT. Supervising the work and revision of the manuscript: FA.

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Introduction

The Argan tree (*Argania Spinosa* (L.) Skeels) (Sapotaceae), is an endemic species of Morocco and Algeria. This species has biological and ecological interest due to its remarkable adaptation to severe climatic conditions (M'hirit *et al.*, 1998). It is an interesting multi-use tree with important socio-economic characteristics.

This species is characterized by a significant polymorphism. Phenotypic variability of the Argan tree has been studied based on the morphological characteristics of vegetative and reproductive organs in Moroccan populations (Ait Aabd *et al.*, 2011, 2012; Zahidi *et al.*, 2013, 2014). The morphological variability of fruit and stones were the most discriminating criteria for Argan populations (Bani-Aameur *et al.*, 1999; Bani-Aameur & Ferradous, 2001; Bani-Aameur, 2004; Ait Aabd *et al.*, 2012; Belcadi *et al.*, 2017; Metougui *et al.*, 2017). Moreover, the characters « forms of fruits and stones » have revealed a higher level of intra-population variability compared to inter-population variability (Bani-Aameur & Ferradous, 2001; Ait Aabd *et al.*, 2012; Metougui *et al.*, 2017).

The fresh Argan tree fruit is a bay of yellowish colour, the pulp covers a very hard stone (Bellefontaine *et al.*, 2011). The stone are composed of 1 to 5 carpels (chamber), each carpel contains one almond.

The shape and size of Argan tree fruits have been the subjects of several observations and studies since 1897. The first morphological descriptions of this fruit included the obtuse ovoid form (Cornu, 1897) and the obtuse ellipsoid form (Perrot, 1907). Metro in 1952 based on the morphometric parameters distinguished four fruit shapes (oval, oval apical, spherical and long fusiform). Later, Maallah (1992) confirmed the existence of all four identified forms and revealed a fifth one (short fusiform).

The stones description revealed three different shapes; ovoid shape (Cornu, 1897), ellipsoid shape (Perrot, 1907) and the oblong shape (Jaccard, 1926).

Banni Aameur *et al.* (1999), by combining visual parameters with biometric criteria, confirmed the existence of different fruit and stone forms and considered them as relevant descriptors for Argan trees. These phenotypical descriptors were used in the evaluation of diversity and identification of plant material (Ait Aabed *et al.*, 2012; Metougui *et al.*, 2017).

Studies of genetic diversity based in molecular markers confirmed the existence of high genetic diversity within and between populations of the Argan population in Morrocco (Majourhat *et al.*, 2008; El Bahloul *et al.*, 2014; Yatrib *et al.*, 2017; Pakrou *et al.*, 2017; Mouhaddab *et al.*, 2017).

In Algeria, this species is mainly located in the southwest part, in the Tindouf region where it forms natural stand. This stand includes three populations named Touaref Bouaâm, Targant and Merkala. The region is characterized by a Saharan climate, with long drought periods throughout the year. The overexploitation of these stands, worsened by the climate changes, threatens their survival. In addition, the Argan tree's natural regeneration in the area of Tindouf is almost absent and germination rates in the nursery are very heterogeneous (Berka *et al.*, 2011).

The germination capacity of Argan stones depends on the mother tree (Bani-Aameur & Alouani, 1999). The germination rate is a genetic characterization of the (seeds origin) tree (Aya *et al.*, 2011; Rix *et al.*, 2015). Some stone characteristics such as shape and weight may influence germination (Loutfi, 1994; Nouaim & Chaussod, 1995). The Argan tree is known for its great variability in the shape, size and weight of its fruits and stones, which affects the heterogeneity of germination (Lamhamedi *et al.*, 2015). Small, rounded seeds germinated faster than large, flat seeds (Liu *et al.*, 2014). The shape of the seeds affect the physiological quality of the seeds (Adebisi *et al.*, 2005; Cervantes *et al.*, 2016). The germination study based on specific seed classes of particular dimensions has been used in cork oak (Lamhamedi *et al.*, 2006) and also in conifer species (Carles *et al.*, 2009).

The morphological characteristics have been considered a valuable tool for the discrimination of heterogeneous populations (Furat & Uzun, 2010) and related to seedling development (MacLeod & Forey, 2002). Therefore it provides valuable information for breeding programs and for conservation strategies of species (Sarikamis *et al.*, 2010).

A greater understanding of phenotypic variability in the Tindouf population is an important step for the preservation of this rare and endangered species. Our work consists in analyzing the morphological variability of the fruits and stones (dimension, weight, and shaps) between mother-trees as well as by the germination capacity according to the stone morphotypes.

Material and methods

Sampling area

The area of the study is located in the southwestern of Algeria, in Tindouf province, at longitude (28° 27' N and 28°36' N), latitude (8°06' W and 8°12' W) and an altitude of 526 m to 630 m. The region is characterized by a Saharan climate with drought period prolonged throughout the year. Precipitations are very weak and irregular; reaching the highest averages (9.7 and 15 mm) in February and October respectively. The highest average temperature is recorded in July (34°C) and relative humidity in winter reaches an average of 50% (Kechairi, 2009; Kechebar, 2016).

The Argan stand of the Tindouf region is distributed in three populations named (Touaref Bouaâm, Targant and Merkala) (Fig. 1). The population in Touréf Bouaâm is the most populated than the other two. The Argan tree's is distributed along the banks of the streambeds (wadis) in Hamada.

The systematic sampling of the mother trees was done along the streambeds following a transect (Fig. 2). Fruits were collected from 30 adult Argan trees (Tr 1 to Tr 30) in June over a 3-year period (2010, 2011 and 2012). 30 matures fruits were collected separately from each Argan tree (Fig. 3). 30 lots each of 30 fruits and 30 stones were labeled separately with the number of its mother tree. (The stones come from dried and pulped fruits). The sampling was repeating three times (during three years).

Morphological description of the fruits and the stones

Nine morphological parameters were studied: length (FL) (mm), width (FWi) (mm), and weight of the fresh

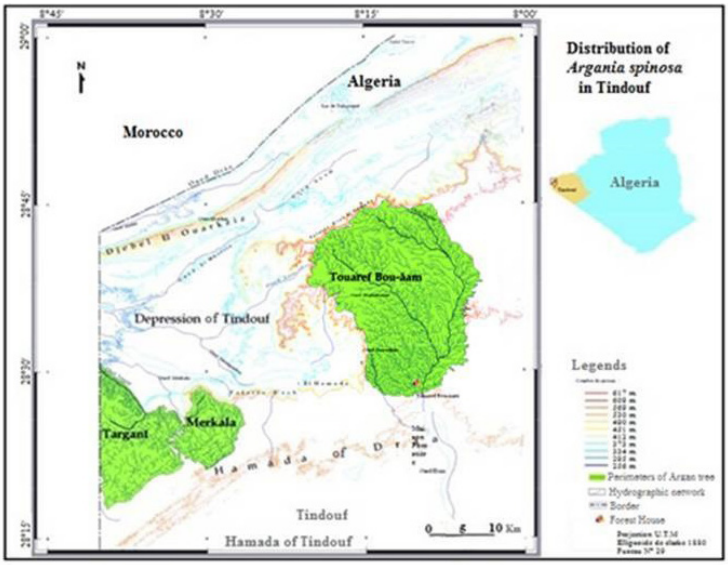

Figure 1. Distribution of *Argania spinosa* in Algeria (Tindouf) (Kechairi, 2009).

fruits (FWe) (g) and length (SL) (mm), width (SWi) (mm), weight (SWe) (g) of the stones. A ratio of width to length of the fruit (fruit ratio, FR) and the stone ratio (SR) were calculated. The number of carpels of each stone was also recorded (CN).

Germination capacity of the stones (GC)

The germination capacity (GC, the maximum rate of germination) was evaluated on stones from 30 mother trees. Four replicates of 25 stones per tree (100 stones) were used for test the germination capacity of each mother tree. The germination capacity was also assessed for various stone shapes (oval, ovoid and spherical). For each shape, 4 replicates of 50 stones were used. The stones were disinfected and soaked in lukewarm water for 24 hours. The germination was carried under controlled conditions (28°C, in the dark) in vermiculite (Berka & Harfouche, 2001), and watered every two days.

Statistical Analysis

The data were statistically analyzed using Excel and Statistica 8. For each studied variable, we determined the mean, maximum, minimum and variation coefficient (CV).

Analysis of variance (ANOVA) with one factor was performed for 10 morphological variables after

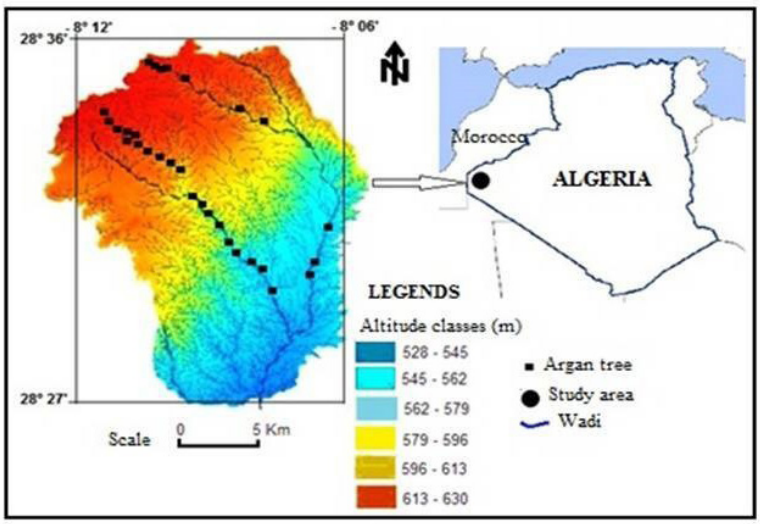

Figure 2. Distribution of *Argania spinosa* mother-trees in the Touaref-Bouâam perimeter (Tindouf).

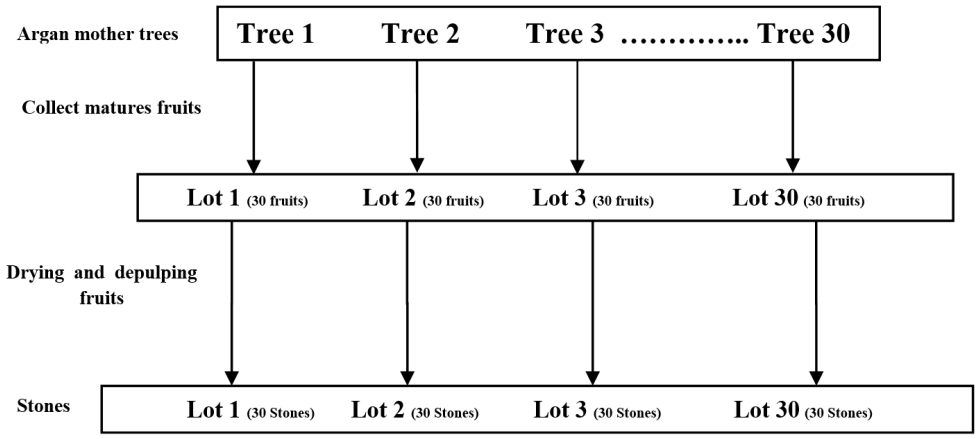

Figure 3. Sampling plan of harvesting fruits and stones from thirty tree of *Argania spinosa* in Tindouf region (Algeria).

normality tests and variance homogeneity. In addition, multiple comparison of means using Newman - Keuls test for the identification of homogeneous groups.

To determine the correlation between the variables, a Pearson coefficient is calculated and a correlation matrix is established.

A Principal Component-Analysis (PCA) was applied to different variables. The projection of all individuals on the principal's axis allow to evaluate the dispersal of these individuals.

Results

Morphological parameters variation of fruits and stones

Fruit morphology

The fruit length varied from 21.30 mm to 45.20 mm for all trees with an mean of 27.96 mm. Analysis of variance highlighted differences highly significant ($p<0.001$). The average multiple comparisons by test of Newman-Keuls allowed distinguishing six distinct groups. The longest fruits come from tree 21 and the shortest from tree 20.

The fruit width fluctuated between 18.00 and 30.2 mm. The mean width for all trees was of 23.28 mm. Analysis of variance showed differences very highly significant ($p<0.001$). Multiple comparisons of averages for this variable have determined 7 homogeneous groups. The tree 21 had the widest fruits and the tree 17 had the narrowest fruits.

The fruit ratio (FR) varied from 1 to 0.57 and the mean ratio for all fruits is 0.85. Analysis of variance revealed highly significant differences ($p<0.001$) for the FR variable. The multiple comparison of the averages allowed distinguishing 5 homogeneous groups. The trees 12 and 1 had the fruits with the highest ratios FR and the tree 3 the fruits with the lowest FR.

The mean fruits weight for all trees is 9.63 g, the weights varied from 6.23 g to 15.14 g. Analysis of variance revealed highly significant differences ($p<0.001$). The multiple comparison of averages by the Newman-Keuls test allowed distinguishing to 8 distinct groups. The heaviest fruits were those of tree 21 and the lightest those of tree 2.

The analyses showed five different shapes of fruits (oval, ovoid, round, spherical and very spherical) (Fig. 4). The oval shape had the highest average length, the lowest average width and the lowest average FR (0.6) (Table 1). The ovoid fruits had an intermediate length and the highest average width and so high ratio (FR) (0.7). Round and spherical fruits are characterized by low average lengths however average ratios (FR) are higher than others shapes (0.8) (Table 1). Fruits with very spherical shape have intermediate length and width and higher ratio (FR) as regards other shapes.

Very spherical and round shapes are most abundant with 30.50% and 30.43 % respectively (Fig. 5), while the oval shape is the rarest with only 4.01% of the harvested fruits. The frequency of spherical and ovoid shapes is 19.5 and 16% respectively.

Stones morphology

The stones length fluctuated between 15.15 mm to 25.54 mm with an mean of 18.02 mm. Analysis of variance showed significant differences ($p<0.001$) between trees. The average multiple comparisons determined five homogeneous groups. The longest stones corresponded to trees 26 and 8, and the shortest to trees 12 and 30.

a b c d e

Figure 4. Fruit shapes of *Argania spinosa* (a: oval; b: rounded; c: ovoid ; d: very spherical ; e: spherical).

The mean stones width for all trees is 13.21 mm, means varied from 16.97 to 11.27 mm. Analysis of variance revealed highly significant differences ($p<0.001$) between trees. The multiple means comparison determined 7 homogeneous groups. Tree 26 had the widest stones and tree 3 had the narrower stones.

The stone ratio was also very variable between the different trees. The mean ratio of stone for all the trees was 0.74. The averages varied from 0.55 to 0.89. The stones with the highest ratio corresponded the trees 1 and 30 and the lowest to trees 3 and 10. Analysis of variance showed highly significant differences ($p<0.001$) between trees. The multiple comparison of means has individualized four distinct groups.

The mean stones weight for all trees is 2.80 g, means vary from 3.75 g to 1.95 g. Analysis of variance showed very significant differences ($p<0.001$) between trees. The multiple comparison of averages distinguished 5 homogeneous groups; the tree 26 has the heaviest stone and the tree 1 the lightest stones.

The number of carpels per stone is very variable from one tree to another. The mean number of carpels per stone for all trees is 1.85 carpels. The highest number of carpels (2.95 C) corresponded to tree 30 and the lowest (1.07 C) to trees 3 and 10. Analysis of variance revealed

Table 1. Mean, maximum, minimum and coefficient of variation (CV %) of length (FL), width (FWi) in mm and ratio FWi/FL (FR) of *Argania spinosa* fruits shapes.

	Fruit shapes				
	Oval	**Ovoid**	**Round**	**Spherical**	**Very spherical**
FL (mm)					
Mean	35.1 ± 2.1	31.3 ± 2.2	30.01 ± 1.3	28.9 ± 2.1	21.5 ± 2.5
Maximum	40.0 ± 3.0	35.8 ± 2.2	33.2 ± 0.2	34.0 ± 1.2	25.0 ± 3.2
Minimum	30.7± 1.2	24.7 ± 1.0	24.02 ± 3.0	24.5 ± 0.2	18.0 ± 2.2
CV %	8.9	9.6	6.6	10.05	6.5
FWi (mm)					
Mean	21.5 ± 1.2	26.4 ± 3.2	24.05 ± 2.2	25.6 ± 3.2	21.6 ± 1.2
Maximum	28.3 ± 3.0	28.5 ± 1.2	30.21 ± 4.2	31.5 ± 0.2	27.0 ± 2.2
Minimum	19.0 ± 3.2	20.2 ± 2.2	21.09 ± 3.2	20.5 ± 0.2	25.0 ± 3.2
CV %	9.8	8.5	8.6	9.8	3.7
FR					
Mean	0.6	0.7	0.8	0.8	1,0
Maximum	0.7	0.8	0.9	1,0	1,0
Minimum	0.5	0.6	0.6	0.7	0.9
CV %	4.3	1.66	3.5	1.7	1.6

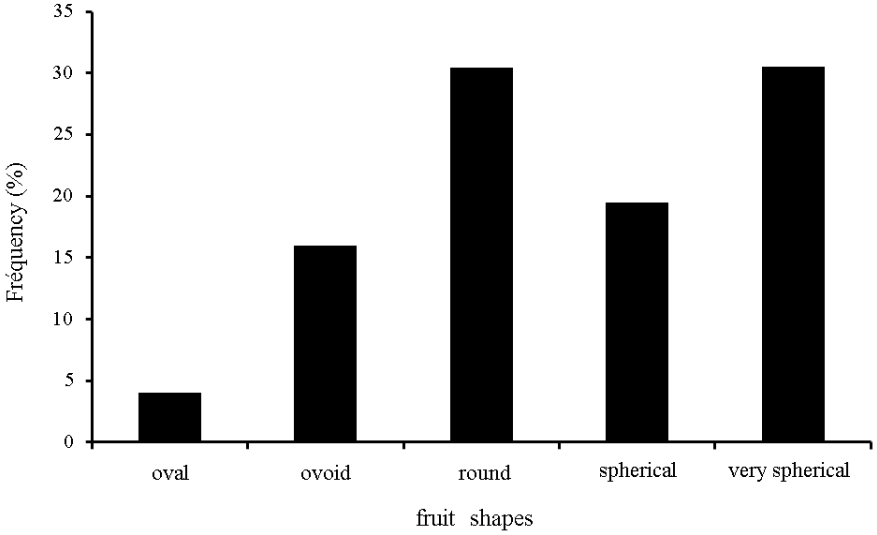

Figure 5. Frequency distribution of fruit shapes of *Argania spinosa* of the Tindouf region as a function to the different shape of the fruits (oval, ovoid, round, spherical and very spherical).

highly significant differences ($p<0.0001$) between trees. The multiple comparison of the averages for this parameter distinguished 5 homogeneous groups.

We also identified three shapes of stones (oval, ovoid and spherical) and two different colours (light brown and dark brown) (Fig. 6). The results of Table 2 show that the longest stones have an oval shape. They are characterized by lowest average ratio (0.6). The spherical shape gathers the shortest stones; are characterized by the highest ratio (0.8). The ovoid shape of the stones is the intermediate shape with ratio of 0.7.

The frequency distribution shows that the spherical form is the most abundant (52.02%), and the oval (elongated) form is the least frequent (12.81%) (Fig. 7).

However, we report no variation in the fruit and stone shape in each tree; the coefficients of variation are less than 15%.

Effect of harvest year on morphological parameters

The averages for all studied morphological parameters of fruits and stones did not differ over the three years of harvest. The variance analysis showed no significant differences ($F=0.034$ $p>0.5$) among the three harvest years.

Germination capacity of stones

The germination capacity of Argan tree stones was very variable between trees, with highly significant differences ($p<0.001$). It varied from 48% to 100%. Mean for all trees was 80.4%. Averages multiple comparisons by Newman-Keuls' test allowed distinguishing 5 homogeneous groups.

The germination capacity also depending on the stone shape. The highest germination capacity was

Figure 6. Stone shapes of *Argania spinosa.* a: Light brown oval; b: Dark brown ovoid; c: Light brown ovoid; d: Light brown spherical; e: Dark brown spherical.

Table 2. Mean, maximum, minimum and coefficient of variation (CV %) of length (SL), width (SWi) in mm and ratio SWi/SL (SR) of *Argania spinosa* stone shapes.

	Stone shapes		
Dimensions	**Oval**	**Ovoid**	**Spherical**
SL (mm)			
Mean	24.83 ± 2.20	21.82 ± 1.2	20.11 ± 2.10
Maximum	30.04 ± 3.10	25.97 ± 3.1	24.17 ± 2.30
Minimum	20.85 ± 2.10	16.68 ± 2.2	16.13 ± 5.10
CV %	7.1	8.0	8.0
Swi (mm)			
Mean	15.06 ± 2.1	15.27 ± 2.0	16.20 ± 1.2
Maximum	19.29 ± 1.1	19.74 ± 3.0	21.27 ± 1.1
Minimum	12.35 ± 3.1	12.12 ± 2.3	13.8 ± 2.2
CV %	4.4	6	7.5
(SR) SWi/SL			
Mean	0.6	0.7	0.8
Maximum	0.7	0.8	1
Minimum	0.5	0.6	0.7
CV %	3.01	3.57	3.6

that of spherical stones with 98.0 ± 2.2% (Fig. 8). That of ovoid-form stones was 70.0 ± 1.2%, while the germination capacity of oval (elongated) stones is the lowest (51.0 ± 0.9%). Subsequently, there was a strong correlation between germination capacity and stone ratio (Table 3).

Multivariate analysis

A strong correlation was noted between morphological parameters of fruits and stones (Table 3). The length of the fruit is highly correlated ($p<0.001$) positively to weight and length stones and negatively to fruit ratio. The stones ratio is positively correlated to the width of stones and negatively to stones' length. A highly significant and positive correlation ($p<0.001$) was found between the ratio of stones and number of carpels on the one hand and at germination capacity of stones on the other hand. The number of carpels was strongly correlated ($p<0.001$) to germination capacity. There were also highly significant correlations ($p<0.001$) between fruits and stones traits, particularly their ratios (Table 3).

The Principal Component Analysis (PCA) provided three axis representing 81,72 % of the total variance.

The variables (FR, SR, GC, CN) were in the negative part of axis 1 and variables (SL, FWe, FL) were in the positive part of axis 1 (Fig. 9), gathering 51,88 % of the total variance. Variables (FWi) and (SWi) were negatively correlated to axis 2 which accounted for 18,05 % of the total variance (Fig. 9).

The stones weight (SWe) was correlated to the positive part on axis 3 (Fig. 9). The two main axes allowed to differentiate 4 distinct groups of trees (A, B, C, D). Group A situated on the positive side on axis 1 composed of 6 tree characterized by long, wide and high weight fruits. Group B is on the negative side on axis 1 and 2 these trees are characterized by the widest and shortest fruits, low weight and high FR. Group C trees are situated on the positive side on axis 2 and negative on axis 1. They are characterized by very short fruits with high ratio and very low weight. Trees of group D are situated on positive side on axis 1 and 2. This group consists of five trees. Their fruits are very long, narrow, low ratio and high weight.

Trees of groups A and D are characterized by large stones (long and wide) of ovoid shape and (long and

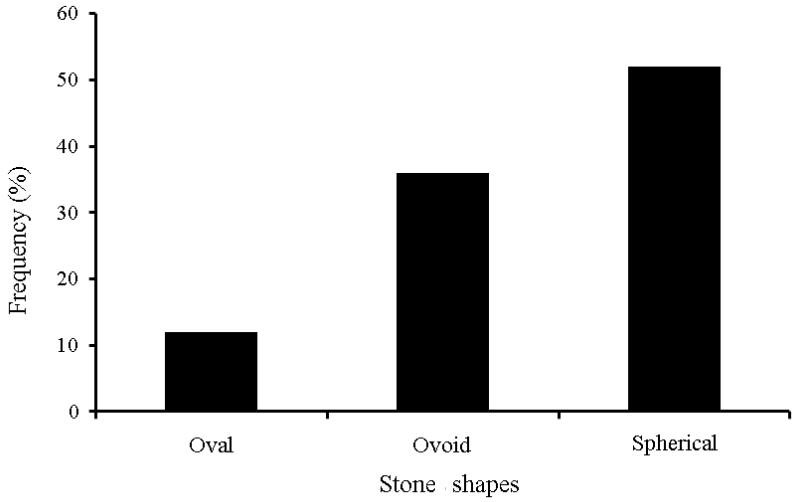

Figure 7. Frequency distribution of the stone shapes of *Argania spinosa* of the Tindouf region as a function to the different shape of the stone (oval, ovoid and spherical).

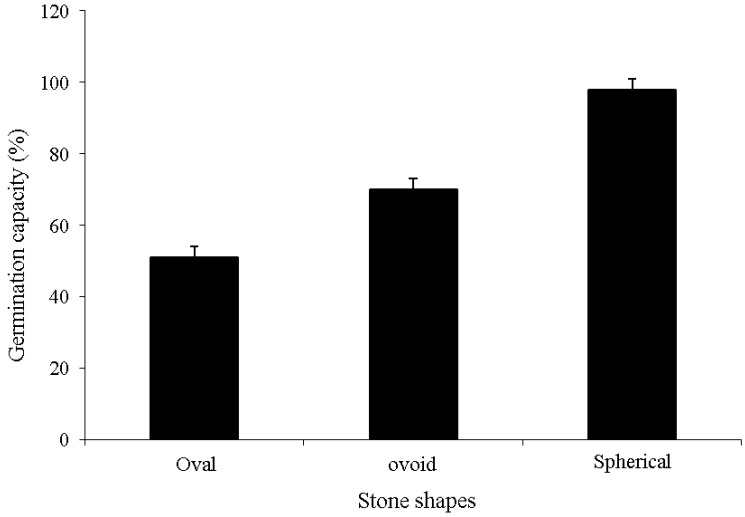

Figure 8. Germination capacity of stones of *Argania spinosa* of the Tindouf region as a function to the different shape of the stone (oval, ovoid and spherical).

thin) oval shape. The stones of both groups have reduced number of carpels and a low germination capacity. Germination capacity of oval (elongated) stones is the lowest (51.0 ± 0.9%) (Fig. 8). In contrast, trees in group B and C have the smallest stones (short and wide), are characterized by high number of carpels and high germination capacity of stones. The most significant germination capacity was obtained with 98 ± 2,2 % spherical stones (Fig. 9). The germination capacity varies according to the shape and dimensions of Argan stones.

Discussion

Our results showed a high morphological variability of the fruits and stones in the Argan tree population of Tindouf. In fact, significant differences were highlighted between trees for each morphological characters of fruits and stones and high correlations between traits.

Different forms have been identified in mothers-trees. The dimensions and forms of fruits and stones of Argan tree are the most discriminate characters in the differentiation of Argan tree genotypes (Ait Aabd *et al.*, 2010; Metougui *et al.*, 2017). Five fruit shapes (oval, ovoid, rounded, spherical and very spherical) and three stone shapes (oval, ovoid and spherical) was identified. The morphometric variation of seeds and fruits was observed in other species such as *Picea glauca* (Carles *et al.*, 2009), *Prunus nepaulensis* (Shankar & Synrem, 2012); *Balanites aegyptiaca* (Abdoulaye *et al.*, 2016).

The variability of fruit and stone shapes observed in most of the Morocco Argan tree populations is also found in the population of Tindouf, except for the narrowly ellipsoidal shape of the fruit with an average ratio of 0.5 (Bani-Aameur, 2004).

Table 3. Correlation matrix between the morpho-physiological parameters of fruits and stones *Argania spinosa* of the region of Tindouf. r = 0.35 for α < 0.05 (*) ; r = 0.45 for α < 0.01 (**) ; r = 0.62 for α < 0.001 (***).

	FL	FWi	FR	FWe	SL	SWi	SR	SWe	CN	GC
FL	1,00									
FWi	0,30	1,00								
FR	**- 0,75** ***	**0,40****	1,00							
FWe	**0,85** ***	0,09	**- 0,77** ***	1,00						
SL	**0,64** ***	- 0,18	**- 0,74*****	0,66	1,00					
SWi	0,03	**0,39****	0,27	-0,09	0,08	1,00				
SR	-0,50	**0,38** *	**0,77*****	- 0,60	**- 0,75****	**0,59****	1,00			
SWe	0,04	-0,11	- 0,12	0,03	-0,07	-0,02	0,02	1,00		
CN	- 0,43	0,41 *	**0,74*****	**- 0,54** **	**- 0,66*****	**0,46** **	**0,86*****	-0,05	1,00	
GC	-0,45	**0,51****	**0,78*****	**- 0,48****	**- 0,60** ***	**0,53****	**0,83*****	0,01	0,73***	1,00

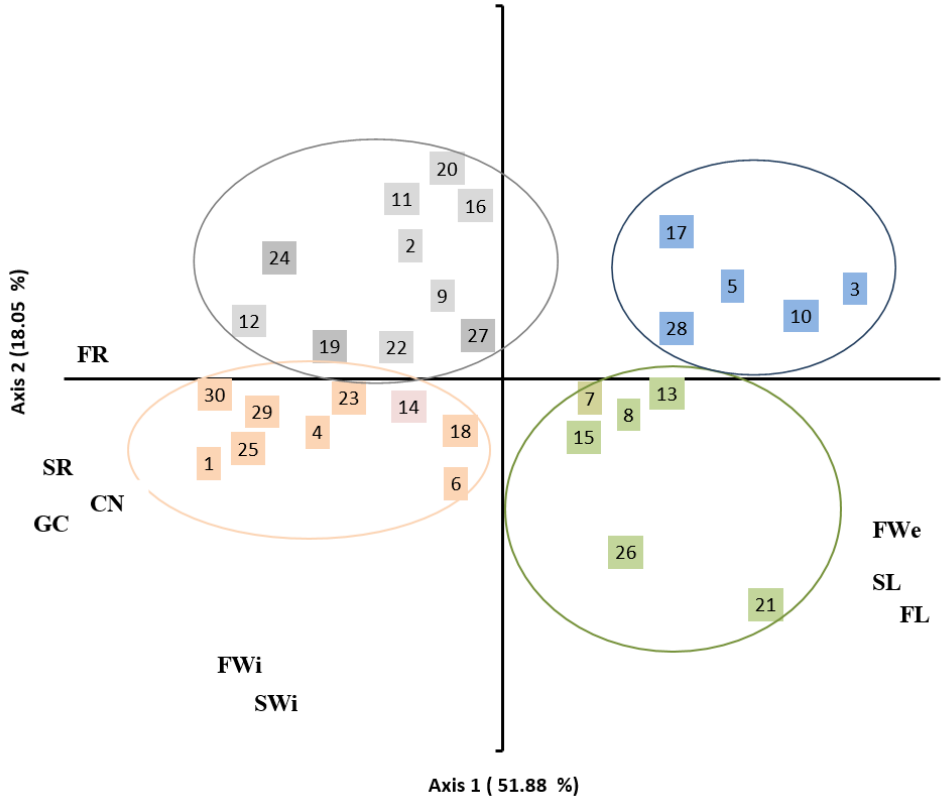

Figure 9. Principal Component Analysis for the 10 selected variables of fruits and stones. Projection of trees on the two main axis (Cumulate variability 69.90%) are shown. Circles in different colors show 4 homogeneous groups of *Argania spinosa* trees according to selected variables (Table 1 and Table 2).

The Argan stones of the Moroccan populations are composed of 1 to 5 carpels (Bellefontaine *et al.*, 2011), while the Tindouf population has a maximum of 4 carpels.

In the studied population, fruit and stone shapes tend to be rounded, very spherical and spherical; the oval shape is the least frequent. Whereas, in most of the Moroccan populations, the oval form is the most frequent and spherical and very spherical forms are the less frequent (Bani-Aameur *et al.*, 1999). The phenotypical characterization of the Argan tree fruits and stones in the Tindouf region allowed us to suggest that this population; located at the extreme limit of North Africa adapted to a Saharan climate; can be different from the Argan tree populations of Morocco.

Fruit and stone traits have a high degree of heritability (an indicator of transmission of a character) (Ait Aabd *et al.*, 2010, Sharma & Kumar, 2013) which confirms the diversity of fruit and stone characteristics of the Argan tree in populations of Morocco (Metougui *et al.*, 2017; Ait Aabd *et al.*, 2010).

Our results also showed that the germination capacity variability of Argan stones is correlated with the stone size and shape. The principal component analysis showed that trees with small and spherical stones have a better germination capacity (98%) than trees with elongated (oval) stones (51%). In the same way, the small-sized and low weight seeds of some tropical species have a high germination rate and are faster germinate than large seeds (Souza & Fagundes, 2014). In fact, the size of the seeds is considered a key factor in the germination and development of some species such as *Copeifera langsdorffi* (Souza & Fagundes, 2014). Unlike in other species as *Cedrus atlantica*, the germination capacity of the seeds is weight-independent (Krouchi, 1995; Aidrous, 2007). The Argan stones are characterized by a thick integument that slows the water imbibition processes (Berka, 2005). The size of the stones is directly related to this thickness and inversely to the water absorption (Beninger *et al.*, 1998). The increase in the seeds size decreases the water absorption capacity and slows the germination process (Fowler & Bianchetti, 2000). Thus, the smallest seeds have a thinner layer and a higher water imbibition capacity (Dolan, 1984).

The significant difference in the germination capacity of the different Argan tree genotypes in the Tindouf region was also observed in the Argan tree populations

in Morocco (Zahidi & Bani Aameur, 1997). The mother tree factor has a significant effect on the germination capacity. There is considerable diversity in genotype responses, emphasizing the importance of the mother tree (seeds source) to use for a successful Argan tree production (Bani Aameur & Alouani, 1999).

The high genetic control of germination is supported by its high heritability (Davidson *et al.*, 1996). Many authors have used heritability to show that germination parameters are under genetic control (El Kassaby *et al.*, 1993; Davidson *et al.*, 1996; Singh & Sofi, 2011).

However, the variability in the morphological characteristics of the Argan tree fruits and stones between harvest years was insignificant. The Tindouf region is characterized by a Saharan climate with extended drought periods. The three years of fruit harvest were dry (no change in the climatic conditions). Similarly, Bani-Aameur & Ferradous, 2001, showed in the Argan tree that inter-tree variation is more important than inter-year variation.

Conclusion

Our results revealed the significant variability of the morphological characters of fruits and stones of Argan between different mother-trees from the Algerian population. The forms of fruits and stones of the Argan tree were similar to those of the Moroccan population except for a higher frequency of the spherical forms. The variation of the germination capacity between mother trees was related to morphological types of the stones, with small spherical stones showing higher germination. These results allow the selection of mother-trees (seed source) suitable for germination to improve the production of nursery plants, successful regeneration programs and ensure the development and preservation of this rare and endangered species. In addition, the morphological diversity evaluation provides relevant information to be added in the future to molecular diversity studies for the conservation of genetic resources at the distribution limit of the Argan tree.

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