

Original Research Paper

Morphometric characteristics of Argan seeds *Argania spinosa* (L.) Skeels in Algeria according to provenances

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Abstract

The aim of this study is to evaluate the biometrics of the Argan seeds *Argania spinosa* (L.) Skeels according to the provenances: Tindouf, Adrar, Timimoun, Bechar and Mostaganem. Therefore, the quantitative variables: length, width, thickness, weight and the number of carpels and one qualitative variable namely colour were measured of 4017 Argan seeds. Principal component analysis reveals the existence of four distinct classes of seeds. The multi-factor ANOVA confirms the significant differences between the regions and highlights the inter-population and intra-population diversity. The planting and exploitation of this multifunctional tree in agriculture in Algeria has many advantages in different fields.

Keywords: Argan seeds, Biometrics, provenance, Anova, Algeria.

Introduction

Algeria has a rich and diverse flora, characterised by a large number of endemic species. This remarkable biodiversity is linked to the existence of highly varied ecological conditions [1]. One example is the argan grove in Tindouf, which perfectly illustrates that Algeria has a variety of biogeographical types at the crossroads of flora of different origins like: Subtropical, Mediterranean and Saharan [2].

The argan tree *Argania spinosa* (L.) Skeels, a hardy and xerothermophilous species, which is the only representative of the botanical family *Sapotaceae* in the North-West of Africa [3-5]. This Algerian-Moroccan endemic [4], is a survivor of the Tertiary flora [6]. It is the most primitive tree in North Africa, as much for its botanical and ecological value as for its social value, which sets it apart from the other forest species. It covers a relatively large area, extending over 50670 hectares to the North-West of the Tindouf region (South-West Algeria) [5], where it is the second most important forest species after *Acacia raddiana* [7].

The argan tree is deeply rooted in the daily life of the Saharan nomads because all the parts of the tree can be used for economic, medicinal and therapeutic purposes [8-11]. Its wood provides excellent charcoal, and its leaves are used as animal forage in the most seasons, but its main interest is that its seeds provide argan oil, the basis of the human diet. Argan seeds come in a variety of distinct shapes, ranging from spherical to elongated spindle-shaped, and including globular, rounded, oval, apiculate oval and drop shapes [12]. This variability presents a higher level of polymorphism, which is due to natural provenances from different biogeographical regions [13]. Some authors have suggested that it is simply a deformation of the seeds due essentially to enzymes [14]. Others say that the genotype

factor is remarkably influenced by provenance [15]. Some authors, such as El Mouhaddab and al. [16], confirm that there is a high level of genetic differentiation between provenances and that morphological features are highly variable from one provenance to another and within the same provenance [17].

The aim of this manuscript is to highlight the polymorphism of the seeds collected from the following regions: Tindouf, Adrar, Timimoun, Bechar and Mostaganem.

Materials and methods

Study area

Argan seed supply sites are spread geographically throughout Algeria, from the north (Mostaganem) to the south (Adrar, Timimoun, Bechar and Tindouf). (Figure 1).

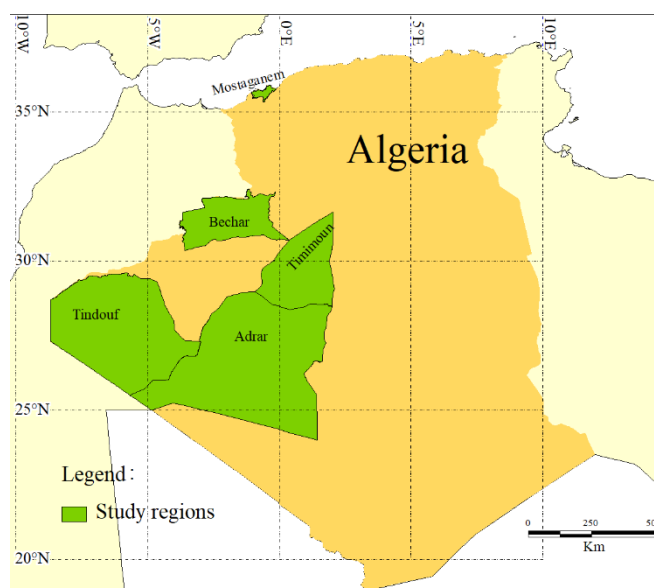


Figure 1. The five regions of provenances studied in Algeria.

For a 30 years period (1986-2016) of meteorological data, particularly temperature and precipitation, the bioclimatic situations of the study regions were established [2, 18, 19], where the argan tree grows in various bioclimatic stages: saharan, arid and semi-arid. The main geographical and bioclimatic characteristics of each site are shown in (Table 1).

Table 1. Characteristics of the study sites (1986-2016).

Regions	Geographical coordinates	Altitude (m)	HR (%)	P(mm)	T°C min	T°C Max	Q2	Floors bioclimatic
Tindouf	28°40'10.9 "N 8°15'41.6 "W	449	45	60,3	7	43	6,55	Saharan
Adrar	27°51.1489"N 000°18.8027"W	281	30	33,5	5	49	2,61	Saharan
Timimoun	29°33'17.1"N 0°09'18.7E	279	26	16	4,4	43,9	1,36	Saharan
Bechar	31°45'23.7 "N 2°14'23.4 "W	780	34	106,3	2	40	9,59	Saharan
Mostaganem	35°52'17.8 "N 0°15'54.2 "E	120	73	371,1	10	35	50,91	Semi-arid

Source: O.N.M

Legend:

T: temperature in (°C); Max: Maximum average for the warmest month in degrees Kelvin (T°C+ 273.15); min: Minimum average for the coldest month in degrees Kelvin (T°C+ 273.15).

Q2: Emberger rainfall quotient.

P: Average annual rainfall in (mm).

Plant material

The plant material consists of argan seeds harvested from five provenances (Tindouf, Adrar, Timimoun, Bechar and Mostaganem). The study was carried out in two research laboratories: Forestry and Genetics at the University of Tlemcen [20]. Biometric measurements of the seeds were carried out during the period from February 2022 to May 2023.

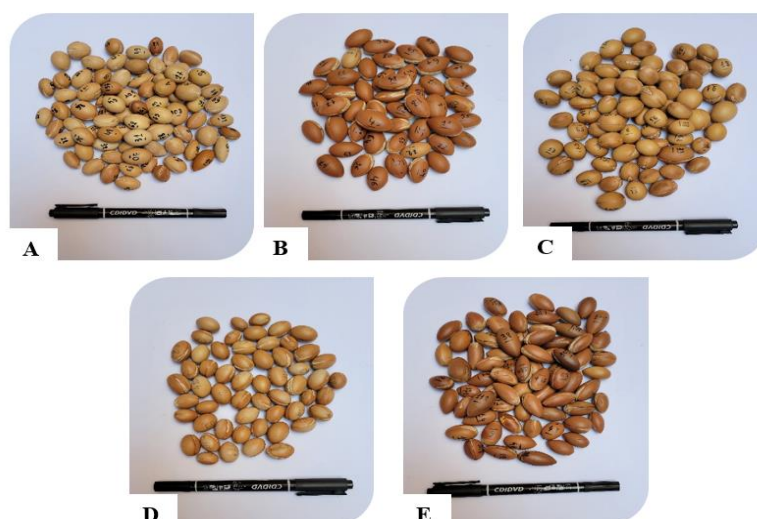


Figure 2. Argan tree cores studied (A: Tindouf, B: Adrar, C: Timimoun, D: Bechar, E: Mostaganem).

Methodology

A set of qualitative and quantitative characteristics were adopted to study the morphometry of 4017 argan seeds from various origins: Tindouf, Adrar, Timimoun, Bechar and Mostaganem (Table 2).

Table 2. Number of argan seeds studied by provenances.

Regions	Number
Tindouf	3139
Adrar	72
Timimoun	504
Bechar	56
Mostaganem	246

The dried fruits brought to the laboratory were crushed with a mortar to obtain seeds. These were marked with numbers so that they could be entered into our database after a set of quantitative and qualitative variables have been measured. For each seed, five quantitative variables were used for characterization: length, width, thickness and number of carpels per seed.

By core, which were measured using a caliper, and the weight was measured using a precision balance. In addition, two qualitative variables were included, shape and color (Brown, Yellowish and Pale).

Statistical analysis

The data collected were subjected to statistical analysis. Namely, normality test (Shapiro-wilk), principal component analysis (PCA), hierarchical ascending classification (HAC) and Anova, using R4.1.2 software (Ref. 2021-11-01).

Results

Statistical analysis

The normal distribution test was carried out before all the statistical tests using the Shapiro-Wilk test. The p-value is equal to 0.05, so our dataset follows the normal distribution.

Descriptive analysis

With regard to the variations (mean $\pm$ standard deviation) of the parameters studied in *Argania spinosa*, we note that there are significant to highly significant differences for the majority of the characters in the regions studied:

The highest average length is noted in the Adrar region with 25.73 mm followed by Mostaganem and Tindouf with 22.16 mm and 21.72 mm respectively, while the lowest length is recorded for the Timimoun and Bechar regions with 20.53 mm and 18.73 mm respectively, For that reported by

Kechairi's study [2] is 24.05 mm for the Tindouf origin, the value cited for the same origin by the study realized by Berka and *al.* [21], was 18.02 mm.

The highest average widths were found in the Adrar, Timimoun and Tindouf regions, with 15.83 mm, 15.77 mm and 15.54 mm respectively. On the other hand, in the study carried out by Kechairi [2], the average for this parameter in Tindouf area was 17.19 mm, the value quoted for this parameter in the study realized by Berka and *al.* [21] was 13.21 mm for the same source.

The average thickness for the five provenances studied (Tindouf, Adrar, Timimoun, Bechar and Mostaganem) is (15.08 mm; 14.58 mm; 15.28 mm; 13.43 mm and 12.78 mm) respectively, where as that reported by Kechairi [2], was 16.72 mm at Tindouf's origin.

The average weight for the five provenances studied (Tindouf, Adrar, Timimoun, Bechar and Mostaganem) is (2.77 g; 3.10 g; 2.71 g; 1.92 g and 2.23 g) respectively, comparing to the study done by Kechairi [2] it was slightly heavier (3.58g) for Tindouf's region.

The number of carpels varies greatly from one to tree. The highest average is recorded in Timimoun region (2.27 carpels) while the lowest average number of carpels is noted in Adrar region (1.29 carpels), while that reported in the study done by Berka and *al.* [21], it was 1.85 carpels for the Tindouf's origin.

Table 3. Descriptive results of the five variables.

	Characters	Mean $\pm$ Ecartype	Minimum	Maximum	Median
Tindouf	Length (mm)	21,72 $\pm$ 2,73	14,54	35,78	21,33
	width (mm)	15,54 $\pm$ 2,36	10,49	28,64	15,11
	Thickness (mm)	15.08 $\pm$ 2.41	9,63	25,35	14,53
	weight (g)	2,77 $\pm$ 1,14	0,72	14,35	2,44
	Carpels	2,04 $\pm$ 0,95	1,00	5,00	2,00
Adrar	Length (mm)	25,73 $\pm$ 1,30	23,41	29,68	25,55
	Width (mm)	15,83 $\pm$ 1,16	12,25	19,59	15,56
	Thickness (mm)	14.58 $\pm$ 1.29	13,08	19,51	14,11
	Weigh (g)	3,10 $\pm$ 0,66	1,87	5,70	3,00
	Carpels	1,29 $\pm$ 0,70	1,00	3,00	1,00
Timimoun	Length (mm)	20,53 $\pm$ 1,85	9,97	28,05	20,49
	Width (mm)	15,77 $\pm$ 1,62	11,82	20,94	15,68
	Thickness (mm)	15.28 $\pm$ 1.62	10,03	20,76	15,32
	Width (g)	2,71 $\pm$ 0,62	1,02	5,76	2,61
	Carpels	2,27 $\pm$ 1,10	1,00	5,00	3,00
Bechar	Length (mm)	18,73 $\pm$ 1,59	15,13	21,54	18,90
	Width (mm)	13,75 $\pm$ 1,12	10,84	15,74	14,01
	Thickness (mm)	13.43 $\pm$ 1.04	10,53	15,64	13,56
	Width (g)	1,92 $\pm$ 0,45	0,91	2,76	1,90
	Carpels	1,66 $\pm$ 0,92	1,00	3,00	1,00
Mostaganem	Length (mm)	22,16 $\pm$ 3,51	15,24	32,37	21,98
	Width (mm)	13,53 $\pm$ 1,41	9,82	17,78	13,48
	Thickness (mm)	12.78 $\pm$ 1.38	8,50	18,24	12,73
	Width (g)	2,23 $\pm$ 0,66	0,83	5,11	2,16
	Carpels	1,31 $\pm$ 0,69	1,00	3,00	1,00

Principal component analysis (PCA)

Principal Component Analysis (PCA) was performed on a matrix containing 8 columns and 4017 rows. This is a very useful method for obtaining a global view of a matrix. In order to analyze the morphological variability of the argan seed, we took into account the inertia rate of the axes and the specific contributions of each variable.

Inertia distribution

The inertia of the first dimensions indicates whether there are strong relationships between the variables and suggests the number of dimensions to be studied. The first two axes of the analysis express 84.84% of the total inertia of the data set, this means that 84.84% of the total variability of the cloud of individuals (or variables) is represented in this plane. This is a high percentage and the first plane therefore represents a significant proportion of the variability of the data. This value is much higher than the reference value of 41.79%, so the variability explained by this design is very significant. On the basis of these observations, it is probably not useful to interpret the following dimensions.

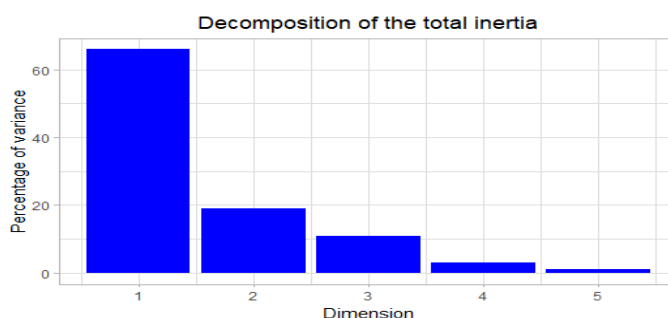


Figure 3. Decomposition of the total inertia.

An estimate of the relevant number of axes to be interpreted suggests restricting the analysis to a description of the first 2 axes. This observation suggests that these two axes carry real information.

Table 4. Percentage of variance for each dimension.

Dimension	Dim 1	Dim 2	Dim 3	Dim 4	Dim 5
Percentage of variance	65,960	18,877	10,969	3,030	1,164

Description of the PCA

The PCA of the variables studied gives us information that the continuous line variables are the active variables. The labelled variables are those best represented on the plan and are coloured red (Figure 6). In which, we also noticed in the PCA, that the characteristics studied in this population are close to the circle, apart from the length characteristic, which indicates a high level of statistical significance.

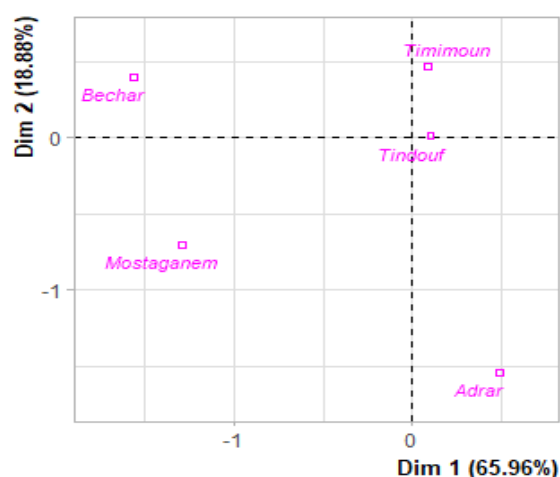


Figure 4. Qualitative factor map (PCA) of the labeled factors are those the best shown on the plane.

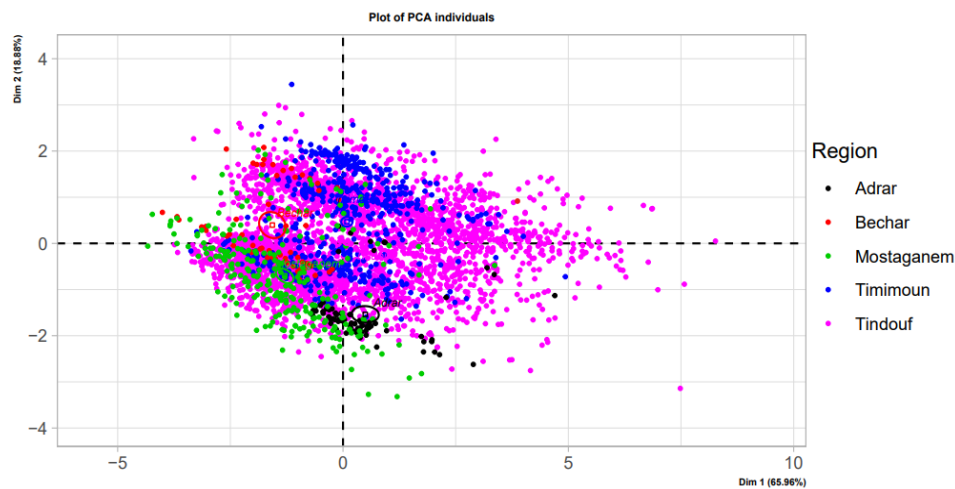


Figure 5. Distribution of the individuals by regions.

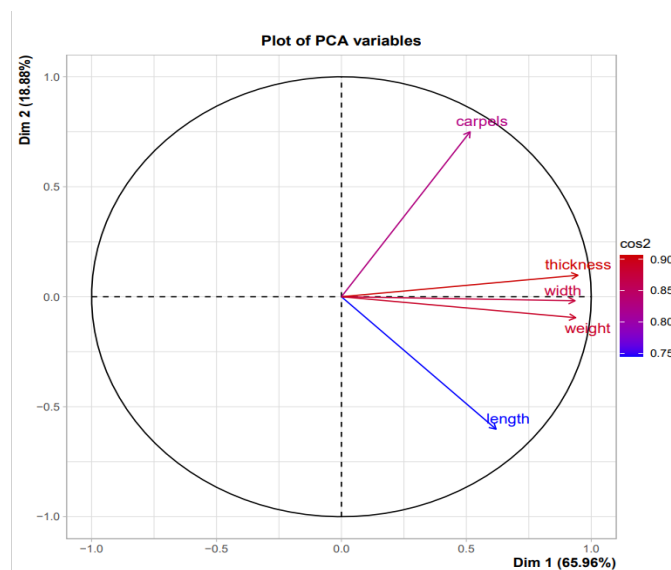


Figure 6. PCA of the variables studied.

Three groups of characteristics can be distinguished. This reflects a positive correlation between these parameters within each group. The first group includes the carpels character. The second group includes thickness, width and weight. The third group consists of the length parameter.

The correlation of these traits can be explained either by the influence of genes, in other words, these traits are controlled by a certain number of genes in common, or these traits react in the same way to environmental conditions. To exclude either probability, we need a situation where the same population evolves in two different biotopes and see if the correlations change. If not, this means that these correlated traits are indeed controlled by a certain number of genes in common.

Hierarchical Ascending Classification

This method allows homogeneity of classes by clustering groups on the basis of similarity or dissimilarity taking into account distances between individuals. Only those variables which have a significant relationship with the classes are shown in Table 5. The intensity of the link (η^2) is measured by the correlation ratio between the quantitative variable and the class variable. Consequently, if this correlation ratio is significantly different from 0, then table 5 shows us the variables that best separate the classes. That means that it characterise the partition (Figure 7).

Figure 7 shows that the four classes are very close to each other, so we can conclude that the individuals in the five classes have certain parameters in common.

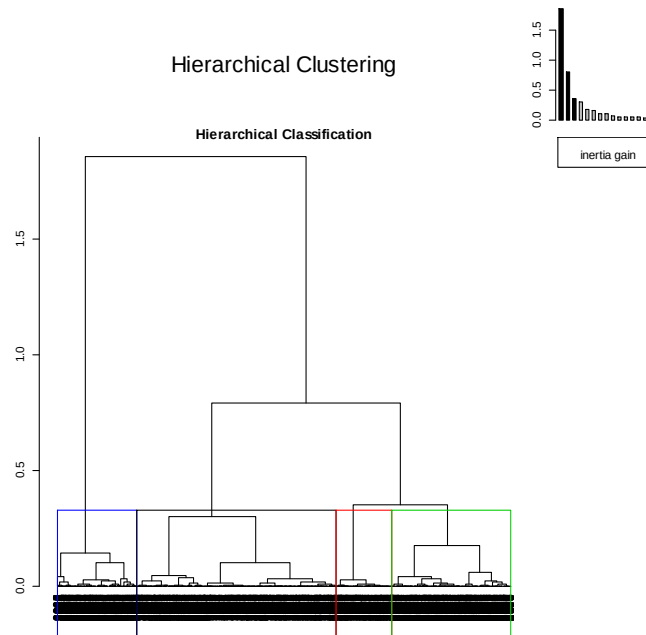


Figure 7. Hierarchical tree of individuals on the factorial plane.

Table 5 therefore shows us the variables that provide the best separation of classes, in other words, that characterize the partition. In this case of study, the variable length is used to best discriminate between the classes obtained.

Table 5. Relationship between the variables studied and the partition.

Parameters	Eta ²
Length	0,461
Width	0,655
Weight	0,691
Thickness	0,684
Carpels	0,767

Table 6. Description of classes by quantitative variables.

	Caracters	v.-test	Mean in category	Overall mean	Sd in category	Overall sd	P. value
Class 1	Length	-24,82475	20,090398	21,629444	1,8251836	2,7687742	4,846821e-136
	Width	-33,92042	13,706144	15,429039	1,1283045	2,2683929	3,331163e-252
	Weight	-34,25857	1,911714	2,724863	0,3408801	1,0600381	3,250742e-257
	Thickness	-37,76185	12,969265	14,931680	1,0964668	2,3209102	0,000000e+00
	Carpels	-42,66805	1,075769	2,009709	0,2702383	0,9775449	0,000000e+00
Class 2	Carpels	39,390400	3,030447	2,009709	0,4285546	0,9775449	0,000000e+00
	Thickness	-5,020361	14,622807	14,931680	1,3546428	2,3209102	5,157444e-07
	Width	-11,605298	14,731189	15,429039	1,4002692	2,2683929	3,873373e-31
	Weight	-12,492750	2,373815	2,724863	0,4970051	1,0600381	8,177699e-36
	Length	-21,480856	20,052826	21,629444	1,6707986	2,7687742	2,351354e-102
Class 3	Length	27,025838	23,881790	21,629444	2,3893664	2,7687742	7,347085e-161
	Weight	7,422743	2,961703	2,724863	0,4647203	1,0600381	1,147192e-13
	Width	7,119150	15,915127	15,429039	1,1874844	2,2683929	1,085944e-12
	Thickness	3,626120	15,185000	14,931680	1,2190177	2,3209102	2,877122e-04
	Carpels	-16,891067	1,512702	2,009709	0,6232229	0,9775449	5,234776e-64
Class 4	Weight	47,24683	4,351690	2,724863	1,0357923	1,0600381	0,000000e+00
	Thickness	47,05999	18,479465	14,931680	1,5641758	2,3209102	0,000000e+00
	Width	46,16694	18,830743	15,429039	1,6712487	2,2683929	0,000000e+00
	Length	25,48586	23,921546	21,629444	2,3631639	2,7687742	2,828154e-143
	Carpels	24,74095	2,795306	2,009709	0,5898568	0,9775449	3,880237e-135

Table 7. Multi-factor ANOVA.

Response: carpels	Sum Sq	Df	F value	Pr(>F)	Sig.
Color	133.33	2	123.12	< 2.2e-16	***
Region	124.07	4	57.2874	< 2.2e-16	***
Shape	965.78	13	137.2071	< 2.2e-16	***
Color:Region	103.96	7	27.4302	< 2.2e-16	***
Color:Shape	97.51	24	7.5036	< 2.2e-16	***
Region:Shape	133.82	12	20.5964	< 2.2e-16	***
Color:Region:Shape	54.98	8	12.6928	< 2.2e-16	***
Response: length	Sum Sq	Df	F value	Pr(>F)	Sig.
Color	531	2	48.8518	< 2.2e-16	***
Region	579.8	4	26.6665	< 2.2e-16	***
Shape	4104.6	13	58.0917	< 2.2e-16	***
Color:Region	322.9	7	8.4883	2.376e-10	***
Color:Shape	707.4	24	5.4228	3.018e-16	***
Region:Shape	541.7	12	8.3062	1.065e-15	***
Color:Region:Shape	59.7	8	1.3736	0.2027	
Response: thickness	Sum Sq	Df	F value	Pr(>F)	Sig.
Color	503.7	2	79.0641	< 2.2e-16	***
Region	418.9	4	32.872	< 2.2e-16	***
Shape	4938.7	13	119.2554	< 2.2e-16	***
Color:Region	292.6	7	13.1233	< 2.2e-16	***
Color:Shape	588.9	24	7.7024	< 2.2e-16	***
Region:Shape	192.6	12	5.0379	0.00000002	***
Color:Region:Shape	127.5	8	5.003	0.00000341	***
Response: weight	Sum Sq	Df	F value	Pr(>F)	Sig.
Color	145.85	2	94.3009	< 2.2e-16	***
Region	50.18	4	16.2223	3.480e-13	***
Shape	713.32	13	70.9565	< 2.2e-16	***
Color:Region	62.16	7	11.4839	1.639e-14	***
Color:Shape	126.35	24	6.8079	< 2.2e-16	**
Region:Shape	37.98	12	4.0933	2.197e-06	***
Color:Region:Shape	23.72	8	3.8343	0.0001669	***
Response: width	Sum Sq	Df	F value	Pr(>F)	Sig.
Color	306.9	2	48.9071	< 2.2e-16	***
Region	437.8	4	34.8837	< 2.2e-16	***
Shape	4989.5	13	122.3208	< 2.2e-16	***
Color:Region	234	7	10.6535	2.37E-13	***
Color:Shape	517.8	24	6.8757	< 2.2e-16	***
Region:Shape	164.8	12	4.3762	5.64E-07	***
Color:Region:Shape	68.7	8	2.7381	0.00518	**

Legend: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.

We were able to deduce that the critical probability of our study is 0.05. Table 6 gives us the information that the variables studied contribute to each class by their discriminating power, when in a class the v-test value of a quantitative parameter is less than (-2), this means that this class obtains a low value (Mean in category) for this parameter compared to a normal individual (Overallmean), the opposite is true. To summarise:

Class 1 is made up of individuals sharing low values for the variables carpels, thickness, weight, width and length (the variables are sorted from the lowest).

Class 2 is made up of individuals sharing high values for the carpel variable, and low values for the length, weight, width and thickness variables (the variables are sorted from the lowest).

Class 3 is made up of individuals sharing high values for the variables length, weight, width and thickness (the variables are sorted from the highest), and low values for the variable carpels.

Class 4 is made up of individuals sharing high values for the variables weight, thickness, width, length and carpels (the variables are sorted from the highest).

ANOVA of the studied population

Statistical analysis using ANOVA showed that there were significant to highly significant differences between the four characteristics studied (length, width, thickness and weight).

Anova also revealed that the interaction between sources, shapes and colors had a significant effect ($p < 0.01$) on the thickness, width, and weight of the seeds. According to Said Ali and *al.* [22], argan seed weights showed significant differences in provenance. There is no difference between the four regions in terms of seed length. According to Louati et al. [23], it is possible to detect a very high level of morphological polymorphism in argan seed. The weights of argan seeds showed significant differences in relation to origin. However, no difference was found between the four regions with regard to seed length.

Discussion

Analysis of morphological characteristics (qualitative and quantitative) showed a high degree of variability both within and between provenances. This variability can be attributed to the genetic characteristics of the species and to environmental conditions [23]. With regard to soil conditions, the argan tree grows in all types of soil and tolerates a wide range of pH values, from 4 to 8.3, as well as high concentrations of limestone [7].

Differences within provenance may be due to climatic conditions. Also, the Saharan climate characterises the three provenances Adrar, Timimoun and Béchar, and another region situated in the semi-arid zone for the Mostaganem provenance. According to Ferradous and *al.* [24], the influence of climate on the weight of argan kernels is due to rainfall. Compared with the Tindouf provenance, where the natural population of argan trees is characterised by great plasticity in terms of adaptation to the geographical area, this indicates the involvement of genetic effects on morphological characteristics. According to Kaushik and *al.* [25], the study of seed biometry in natural populations is useful for studying genetic variability [26].

For the majority of morphological characteristics, significant differentiation was observed between provenances, which can be judged by the combined influence of climatic conditions and geography. Finally, in-depth phylogenetic research is needed to better understand the polymorphism of the argan tree within the Tindouf argan grove.

Conclusion

The aim of the study was to analyse phenotypic diversity based on morphological characteristics of species collected in the wilayas of Tindouf, Adrar, Timimoun, Bechar and Mostaganem. There is therefore a high level of diversity in terms of highly polymorphic characteristics, namely length, width, thickness, weight, number of carpels, color and provenance. We can say that the argan is a tree of the future and can be located in bioclimatic stages ranging from semi-arid to Saharan. The prospects for our work are the preservation and planting of this species in the arid and semi-arid region of Algeria, because of its ecological plasticity and resistance to desert conditions and the fight against desertification, and to advance agricultural and economic development in Algeria.

Author's Contributions: Bendellaa H.: Measurement, Writing and interpretation, Main author, Correspondence. Kechairi R.: Data collection, Project coordinator and processor, Review. Megharbi A.: Interpretation, Statistical analysis, Review. Kholkhal D.: Interpretation, Review. Dich I.: Interpretation, Statistical analysis, Review. Allaoui H. and Azzaz G.: Measurement.

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