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GENETIC VARIABILITY AND HERITABILITY ESTIMATES FOR LEAVES TRAITS IN (*AGRANIA SPINOSA* (L.) SKEELS) SEEDLINGS AT NURSERY STAGE

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ABSTRACT

Genetic variability and differentiation of eight characters of simple leaves were observed in argan seedlings grown in nursery for 12 months using open-pollinated seed collected from three geographical origins. Contribution related to geographic origin, block and their interaction in the total variance was low for all traits (0% to 6.13%). The contribution of family / provenance (inter-family variance) in the total variance was higher for all characters except for petiole length. This variance is lower than that related to differences between seedlings in the same family (intra-family variance). Values were ranged from 44.5% and 73.0% for most characters. Seedling leaves of some families were longer, wider, with more secondary veins and with ratio and leaf areas very important. Narrow sense heritability was higher for most traits and ranged between 0.35 for leaf width to 0.66 for leaf area. Differentiation between the three populations for morphological leaf traits in argan seedlings is not established. Diversity is mainly due to differences between seedlings within families in each population. Understanding leaf traits provides a database for genetic improvement of agro-morphological characters given that argan tree is source of food for a large number of herds especially in times of drought in arid environments.

Keywords: *Argania spinosa*; Seedling Leaves; Genetic Diversity; Differentiation; Multivariate Analysis

INTRODUCTION

The argan tree, *Argania spinosa* (L.) Skeels, is a threatened species which is endemic to south west Morocco. Stands cover around 830 000 hectares of an arid area affected by intense human pressure. Efforts to develop production are encouraging users of the resource to preserve it and are thus contributing to socio-economic development in the region. The use of argan leaves in cosmetics is an additional possibility **[1-4]**. Aridity is a major challenge and permanent for this species since drought may be extended for several consecutive years **[5-7]**. Studies of morphological characters are recent and interested trees in their natural domain. Six fruit forms and three kernels shapes **[8]**, four leaf shapes and five morphological types of tree habit **[7]** have been described in three populations Ait Melloul, Argana and Ait Baha. Repeatabilities (broad sense heritability) were variable in large proportions for fruit and kernel characters **[8]**, for branching and foliation traits **[7]**. Differentiation for the three populations is not established but considerable heterogeneity between genotypes within the same locality is noted. Similar results were obtained for nine traits of simple and grouped leaves observed for three consecutive years in argan at three natural populations in the field **[9]**.

The necessity to obtain sufficient informations concerning morphometric characters in order to assess the magnitude of genetic variability and their corresponding heritability are imperative for any successful breeding program as was done in several plant species. In order to select plus trees for some characters as branching, growth in length, oil production and others, analysis of genetic variability, broad and narrow sense heritability were studied **[10-12]**. In argan, study of molecular markers for nine isozyme loci in 232 seedlings in ten populations revealed a high level of diversity. High differentiation was noted especially in peripheral populations (Beni Snassen and Goulmime) **[13]**. In field, study of 90 trees originated from three sites shows that climatic year was significant only for leaf width and leaf area of both leaves of trees. This effect was greater in dry and warm year than in humid years, by reducing width and leaf area. Genotype (tree / locality) and genotype x environment interaction (year x tree / locality) were highly significant for all traits. Their relative percentages in total variance were ranged from 14.9% and 44.3% except for dry weight of simple leaves. Broad sense heritability was higher for most characters, and ranged from 21.7% to 57.9% respectively for width and leaf length **[14]**. Researches on variability and differentiation for leaf characters of argan seedlings are absent. This work is a contribution in this direction. The aim was to study genetic diversity and estimating narrow sense heritability in argan seedlings at nursery stage.

MATERIALS AND METHODS

Plant Material

Kernels are from mature fruits harvested in summer for two consecutive years in three geographical origins in south west Morocco, Ait Melloul (AM), Argana (AR) and Ait Baha (AB) **[7]**. Almonds from 29 families in each site, with a total of 87 families, are germinated and transplanted according to experimental protocol described previously **[15]**.

Methodology

After one year, five first simple leaves of the part juxtaposed to the apical growing zone of each seedling of ten families per geographic origin and per block were sampled. Leaves are kept fresh in cellophane pouches with number of seedlings, family, geographic origin and block. Four characters are measured in centimeters under binocular loupe (magnification x 20) for more precision using the protocol described previously **[15]**: leaf length (LO), leaf width (LA), midrib length (LNP) and petiole length (LP). It was deduced later the following traits: leaf ratio (RF = LA / LO) and leaf surface as the product (SF = LA x LO). We counted number of secondary veins (NS) and stomata number (ST) on the upper and lower face as described by **[16].**

Statistical Analysis

An analysis of variance with three factors in hierarchical model was performed. Factor family (seedling issued from the same mother-tree) is hierarchical to geographic origin, given that families are not repeated among sites and within the same site. Block and geographic origin are crossed. Averages are compared by method of least significant difference (LSD) **[17, 18]**. Variance components were estimated from the appropriate linear functions of mean squares **[19, 20] (Table 1)**. All factors are considered random in variance calculations. Estimating relative contribution of block, geographic origin, family / geographic origin and their interactions is calculated relative to the total variance ($\sigma^2 t$) **[21-23]**. All factors are considered random in variance calculations.

$$\boldsymbol{\sigma^2_{T} = \sigma^2_{B} + \sigma^2_{PR} + \sigma^2_{B\,x\,PR} + \sigma^2_{F\,/\,PR} + \sigma^2_{B\,x\,F\,/\,PR} + \sigma^2_{B\,x\,PL\,x\,F\,/\,PR} + \sigma^2_{E}}$$

σ^2_{T} : total variance; σ^2_{B} : variance due to block; σ^2_{PR} : variance due to geographic origin; $\sigma^2_{B\,x\,PR}$: variance due to interaction block x geographic origin; $\sigma^2_{F\,/\,PR}$: variance due to family / geographic origin (inter-family variance); $\sigma^2_{B\,x\,F\,/\,PR}$: variance due to the interaction block x family / geographic origin; $\sigma^2_{B\,x\,PL\,x\,F\,/\,PR}$: intra-family variance: genetic variance due to differences between seedlings of the same family; σ^2_{E} ($\sigma^2_{B\,x\,PL\,x\,F\,/\,PR\,X\,SAM}$) : variance due to error.

Each of the four seedlings of each family is derived from germination of kernel collected separately in each of the three localities. In addition, mother-trees of seedling are not repeated between sites, and at the same geographical origin. So variance component related to family is confounded with the genetic variation between localities. Estimating heritability is a relative indication of genotype and environment effects on leaf characters in argan seedlings. Narrow sense heritability is calculated using the following model [**21-22, 24-25]**:

$$h^2 = 4\,\sigma^2_{F/PR} / (\sigma^2_{F/PR} + \sigma^2_{B \times F/PR} + \sigma^2_{B \times PL \times F/PR} + \sigma^2_{E})$$

where variance $\sigma^2_{F/PR}$: expresses inter-family variance (variance due to family / geographic origin), $\sigma^2_{B \times F/PR}$: denotes variance related to block x family / geographic origin interaction, $\sigma^2_{B \times F \times PL/PR}$: means the intra-family variance (variance due to differences among seedlings within the same family) and σ^2_{E}: expresses error variance.

Principal component analysis was performed for seven traits, and stomata number. This analysis is based on averages centered and scaled matrix. Classification of families was performed on averages of eight characters. Classification of localities was made on the averages of ten families in each provenance for all characters. These classifications were made by UPGMA "pair-group method unweighetd arithmetic average". All statistical calculations were performed using Statitcf software, Statistix and Ntsys Version 1.4 **[26]**.

RESULTS

Description of Variability

Block

Block factor was significant for leaf width (LA), leaf surface (SF) and leaf ratio (RF=LA/LO) **(Table 2)**. It was not significant for the other traits.

Geographic Origin

Geographic origin and block x geographic origin interaction were not significant for all characters **(Table 2)**.

Family / Geographic Origin

Block x family / geographic origin interaction has significantly influenced LA, RF, petiole length (LP) and number of secondary veins (NS) **(Table 2)**. It was not significant for the other characters. Block x seedling x family / provenance interaction, which refers to differences between seedlings within the same family, was highly significant for all observed traits. Family / geographic origin (mother-tree genotype) was highly significant for all characters except petiole length. A remarkable variability between families was observed for all seedlings characters at this stage, illustrated by great differences in coefficients of variation **(Table 3)**. For leaf length, midrib length, leaf width, ratio, surface, and number of secondary veins some families from Ait Baha, from Argana, and from Ait Melloul were among the group having leaf dimensions less than average of each character. Two classes of genotypes at this stage of seedling development are distinguished. A first class consisting genotypes such as families 9 and 10 of Ait Melloul, 7 from Argana, and 5, 7 from Ait Baha whose seedlings showed leaves longer, broader, with more secondary veins and with higher leaf ratios and areas **(Table 4)**. Instead, second class of genotypes including families such as 8 from Ait Melloul, 9, 10 from Argana, and 2 from Ait Baha which seedlings were characterized by shorter, narrower leaves, with a smaller number of secondary veins and with lower ratio and areas.

Variance Components

Block

Relative contribution of variance due to block in the total variance was low and ranged between 0% for LO and 6.2% for leaf ratio **(Figure 1)**.

Geographic Origin

Relative percentage of variance related to geographic origin and block x geographic origin interaction in total variance was low for all traits and ranged from 0% for NS and 3.3% for leaf area **(Figure 1)**.

Family / Geographic Origin

The relative contribution of variance related to block x family / provenance interaction in total variance was variable for most characters and ranged from 2.5% and 10.9% for leaf ratio **(Figure 1)**. Contribution of variance related to block x seedling x family/geographic origin interaction (intra-family variability) in total variance was higher for all morphological traits except leaf width (14.4%). It explains a percentage ranging from 44.5% for petiole length and 73.0% for leaf length and midrib length. Argan tree shows a great variability among seedlings within the same family for all traits of simple leaves. This contribution was higher than inter-family variability (family / provenance) which explains percentage ranged from 8.6% for leaf width to 15.5% for leaf area. Narrow sense heritability was lower for petiole length and stomata number, but it was higher and ranged from 0.35 for leaf width to 0.66 for leaf area **(Table 5)**.

Distribution of Variability

Principal Component Analysis (PCA)

Correlations between morphological traits of seedlings leaves at this stage varied in large proportions **(Table 6)**. LO is highly correlated to LNP, SF and LA. LA is correlated in the same direction in varying proportions to SF, RF, LOP and NS. RF is moderately correlated to SF and NS. SF was highly correlated to LOP but with a low degree to NS. The other traits were not correlated.

The three axes of PCA absorb 84.9% of total variability, 71.3% is explained by the first two axes **(Table 7)**. The first axis in relation to an eigenvalue of 4.33, explains 54.2% of the total variability. It is strongly correlated in the positive direction to SF, LA, LO and LOP. Thus, families such as 5 from Ait Melloul, 5 and 6 from Argana and 7 from Ait Baha with leaves

longer, wider, and with greater ratio and leaf area were projected on positive side of the first axis **(Figure 2)**. The second axis in relation to an eigenvalue of 1.4 explained 17.1% of total variability. Most of this variability is related to petiole length. Families such as (5) of Ait Melloul (8 and 7) Argana and (5) of Ait Baha whose leaves have long petioles are at negative side of the second axis. The third axis in relation to an eigenvalue of 1.09 explains 13.6% of total variability. It is strongly correlated in the negative direction to stomata number. Families (2) of Ait Melloul, (9) of Argana, and (2 and 6) of Ait Baha with a low number of stomata are projected on the positive side of the third axis.

Projection in space reveals distribution of families spread out along the three axes. Approximately 6/10 (60%) families from Ait Melloul are among plants having leaves longer and broader, with areas and number of secondary veins remarkable. Families from Argana and Ait Baha are more dispersed along the axes and approximately 7/10 (70%) and 6/10 (60%) have leaves longer, wider and with areas and number of secondary veins more important. There is a mixture of families from three geographical origins. Differentiation between the three populations on the basis of simple leaf characters is not established, but considerable heterogeneity between families was observed at this nursery stage.

Classification Method (Cluster Analysis)

Two major groups are distinguished in a Euclidean distance of 0.31 **(Figure 3)**. The first group contains one family (5) from Ait Baha, which is characterized by relatively short and narrow leaves, leaf area, number of secondary veins and stomata number are also lowers. The second group is divided into two subgroups at a Euclidean distance of 0.19. A first subgroup containing six families (1/6) 10% from Ait Melloul, 3/6 (50%) originate from Argana and (2/6) 33.3% are from Ait Baha site. The second subgroup is divided into two classes. The first class containing seven families with 4/7 (57.1%) originated from Ait Melloul, 2/7 (28.6%) are from Argana and 1/7 (14.3%) from Ait Baha. The second class containing about 5/16 (31.3%) families originated from Ait Melloul, 5/16 (31.3%) families from Argana and 6/16 (37.5%) families originated from Ait Baha. Differentiation between the three populations is not established, but a significant heterogeneity between seedlings in the same family was found. This heterogeneity constitutes a germoplasm in breeding programs of argan as tree with pastoral vocation.

The classification of the three geographical origins can distinguish two groups at a Euclidean distance of 3.1 **(Figure 4)**. A first group formed by Argana site and second group containing Ait Melloul and Ait Baha populations. We reveal that the mountain site (south side of the Western high Atlas) more humid with an autumn and winter cold differs from the two sites climatically similar; Ait Baha (north side of Anti Atlas) and Ait Melloul (valley site).

DISCUSSION

The influence of different sources of variation on seedlings leaf traits varied in large proportions according to character. Geographical origin of kernels had no influence on the morphological criteria of simple leaves. Locality factor have also a lower contribution for branching and growth characters of trees in field **[7]**, and for fruit and stone characters except fruit color **[8]**, for fruit traits and oil production in total of 75 trees observed in five provenances in south west Morocco **[27]**. Similar results were observed for seed length and seed width within nine provenances of western black sea in turkey in *Pinus silvestris* (L) **[28]**. Intra-family variance and inter-family variance (family / geographic origin) explained a percentage between 22.8% and 84.1% of total variance for all leaf characters in argan seedlings at this stage of development. Intra-family variability is greater than variability between families. It is 4 to 6 times greater than the variability between families for all characters except leaf width. Argan shows an important degree of variability in trees progeny. Some seedlings may have leaves longer, wider, with a remarkable number of secondary veins, with ratio and areas more important. While for others families leaves are shorter, narrower, with a low number of secondary veins, and with lower ratio and leaf surfaces. In contrast to results obtained by **[29]** in chestnut trees ('Judia' variety) for morphological and phenological characters where there is little genetic diversity and differences observed are mainly different climatic conditions rather than genetic capacities. Defoliation in argan is a genotypic reaction to water stress, climate site aggravates more or less this reaction **[7]**. Thus to improve production in this species and therefore the productivity of this ecosystem because leaves are the site of photosynthesis, the choice of a genetic material able to produce leaves longer and larger with a great areas in these arid environments is a need. Our seedlings derived from mother-trees able of producing large leaves even in dry years. In addition, the relative contribution of variance associated with genotype x environment interaction (tree x year / locality) in the total variance was higher for all characters in simple and grouped leaves except dry weight. This percentage ranged from 14.9% for leaf length and 40.5% for number of secondary veins. In addition, the relative contribution of variance associated to tree / locality (genotype) in total variance was more important and ranged between 15.1% and 44.3% for all characters of simple and grouped leaves except dry weight (4.5%). Broad sense heritabilities were higher and ranged between 21.7% and 56.7% for all traits except dry weight (4.8%) **[9]**. In this study, narrow sense heritabilities were higher (0.35 to 0.66) and reflect higher diversity level for most traits of simple leaves. These families may therefore be a higher quality genetic material available for any genetic improvement for domestication of argan tree. Similar results were also observed in other species such as in *Jungus hindsii*, in which intra-family variance is higher (more than 3 to 7 times) than inter-families variability. Heritabilities were ranged from 0.47 to 0.88 [**21]**. In *Eucalyptus deglupta*, great variability between families of the three sites studied for height growth and leaf color of seedlings older than 16 months is observed **[24]**. Narrow sense heritabilities (h^2) were ranged from 0 to 0.9 for concentration of micro and macro elements of leaves in *Lolium perenne* (L.) **[30]** and from 0.09 to 0.46 for morphological characters in *Taxus brevifolia* **[22]**. Similar values were also observed (0.05 and 0.47) for height growth traits in *Picea abies* (L.) **[31]**. There were ranged in *Eucalyptus globulus* Labill. Ssp. *globulus* from 0.19 to 0.37 for seedling leaves **[32]**, and from 0.12 to 0.21 in seedlings of *Cupressus lusitanica* Mill. Old than 28-months **[33]**, in white spruce for growth length of stem in seedlings aged than 18 weeks (0.92) **[34]** and in hybrid plants aged 2 to 16 years for which heritabilities were high (> 0.8) for height, volume, branch angle and wood density **[35]**. Families classification is not made in relation to affiliation of mother-trees to their original provenances. Characters that change between provenances and correlated with axis of PCA which explains greatest percentage are primarily leaf length, midrib length, leaf width and leaf area. In addition, each of the main groups obtained by UPGMA, includes individuals from both Ait Melloul, Argana and the arid site Ait Baha. At Argana station most humid with an autumn and winter cold **[6, 7]**, trees have smaller leaves **[9]**. These results can be explained by trees adaptation to mountain conditions including low temperatures.

They join the event reported by **[36]** that low temperatures could induce a slow of the physiological processes of bud break and shoot growth and thus growth of leaves in trees. This observation is found in progeny derived from mother-trees originating from Argana, since seedlings produce shorter leaves, with smaller ratios and surfaces. Thus argana site is well separated from the two populations Ait Melloul and Ait Baha. Differentiation for leaf traits in argan seedlings is not established. Most of diversity is related to differences between families and between genotypes of seedlings within the same family. We observe more heterogeneity between plants in different families from the two mountain sites characterized by changes in climatic conditions (cold winter at Argana and a summer drought in Ait Baha) compared to the valley station (Ait Melloul) subject to oceanic influences and where temperatures are milder. Such distribution pattern is not observed in *Azadirachta indica* (A. Juss.) **[37]**. In this species, leaf length and leaf surface differed between populations in North compared to those in South. In *Prunus cerasus* (L.) length, width, leaf area and petiole length distinguish the 28 families studied according to the first axis of PCA which explains about 50% of the total variability (83% for the three axes) **[38]**. The same pattern of distribution has been noticed in *Taxus brevifolia* for morphological characters **[22]**, in *J. californica* and *J. hindsii* for biometric traits **[21]**. In seedlings of *Q. petraea* and *Q. robur*, leaf characters (hair density and angle of blade) lead to discrimination between two species of oak at young seedling stage **[39]**. **Bhargava *et al*., 2008, [40],** showed that the first 4 principal components accounted about 74.70% of total variance among the accessions of *Chenopodium spp*. The first PC (PC1) accounted for 41.96% of total variation. Nickel, zinc and chromium have presented high positive coefficients but copper showed high negative coefficients. The most important loadings for PC2 were calcium and potassium. Four major clusters characterized by different levels of metals were observed. In argan tree, similar results were found for molecular markers of seedling leaves of ten populations in argan area **[13]** where there are similarities among nearest populations as Argana, Ait Baha and admine. These results will be helpful in efforts to develop production are encouraging users of the resource to preserve it and are thus contributing to socio-economic development in the region. The use of argan leaves in cosmetics is an additional possibility as reported by **[4].**

CONCLUSION

For simple leaves in argan seedlings grown in nursery for 12 months, inter-family variance is lower than the intra-family variance. Differentiation for morphological characters is not established. Classification of families does not coincide with the belonging to original provenances. But, there are two categories of genotypes. Seedlings of some families from Ait Melloul and Ait Baha are able to producing longer, broader leaves and with greater ratios and areas. But others families were able to producing leaves shorter, narrower, and their ratio and area is particularly low. At Argana site characterized by a cold winter, mother-trees of seedling have also leaves with small sizes. Between these two extremes, intermediate genotypes exist. These results on leaf traits provides a database for genetic improvement of agro-morphological characters given that argan tree is pastoral vocation and a source of food for a large number of herds especially in times of drought. The advantage of using seedling traits associated with drought tolerance such as leaf area and stomatal density in the context of the restoration of the argan forest in arid areas is the subject of another study which will be published shortly. Moreover, this result has important practical implicaltion for genetic management ressource since several several physical and anthrologenic factors reduce the density and surface of argan ecosystem, so it decreases the biodiversity in natural areas.

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Table 1: Expectations of Mean Squares and Estimated Variance Components of Morphological Characters of Simple Leaves in Argan Seedling

Source of variation	DF	Mean square	Expectations of mean squares
Block	2	CM_B	$\sigma^2_e + 5\sigma^2_{BPlFPr} + 20\sigma^2_{BFPr} + 200\sigma^2_{BPr} + 600\sigma^2_B$
Geographic origin	2	CM_{Pr}	$\sigma^2_e + 5\sigma^2_{BPlFPr} + 20\sigma^2_{BFPr} + 200\sigma^2_{BPr} + 600\sigma^2_{Pr}$
Block x georgaphic origin	4	CM_{BxPr}	$\sigma^2_e + 5\sigma^2_{BPlFPr} + 20\sigma^2_{BFPr} + 200\sigma^2_{BPr}$
Family / georgaphic origin	27	$CM_{F/Pr}$	$\sigma^2_e + 5\sigma^2_{BPlFPr} + 20\sigma^2_{BFPr} + 60\sigma^2_{FPr}$
Block x family / georgaphic origin	54	$CM_{BxF/Pr}$	$\sigma^2_e + 5\sigma^2_{BPlFPr} + 20\sigma^2_{BFPr}$
Block x family / georgaphic origin x seedling	270	$CM_{BxPlxF/Pr}$	$\sigma^2_e + 5\sigma^2_{BPlFPr}$
Block x family / georgaphic origin x seedling x sample (Error)	1440	CM_e	σ^2_e

Table 2: Variance Analysis for Simple Leaves Characters in Argan Seedlings at Nursery Stage

Source of variation	DF				mean square			
		LO	LA	RF	SF	LP	LNP	NS ST
Block	2	0,05 ns	0,14 **	0,09 **	0,36 **	0,0003 ns	0,05 ns	7,87 ns 15,07 ns
Geographic origin	2	0,54 ns	0,09 ns	0,07 ns	0,42 ns	0,0009 ns	0,54 ns	6,84 ns 11,5 ns
Family / geographic origin	27	0,28 **	0,07 **	0,02 **	0,24 **	0,0004 ns	0,28 * *	15 * * 12,75 *
Block x geographic origin	4	0,15 ns	0,02 ns	0,02 ns	0,08 ns	0,0004 ns	0,15 ns	4,42 ns 7,25 ns
Block x family / geographic origin	54	0,11 ns	0,02 *	0,01 **	0,08 ns	0,0004 *	0,11 ns	5,09 * 8,48 ns
Block x seedling x family / geographic origin	270	0,01 **	0,01 **	0,00 5 **	0,06 **	0,0002 **	0,01 * *	3,7 ** 9,30 **
Error	1440	0,003	0,006	0,00 05	0,002	0,00004	0,003	0,34 5,60

NOTE: DF: Degree of Freedom, NS: Not Significant, *: Significant at 5%, **: Significant at 1%

Table 3: Maximum (Max), Minimum (Min), Coefficient of Variation (CV) and Average (Avg) of Leaf Traits in Argan Seedlings by Provenances: Ait Melloul (AM), Argana (AR) and Ait Baha (AB)

Charac-ter		AM				AR				AB				Average		
	Max	Min	CV	Avg	Max	Min	CV	Avg	Max	Min	CV	Avg	Max	Min	CV	Avg
LO (cm)	1,70	0,86	11,24	1,24	1,99	0,72	14,72	1,26	1,68	0,78	11,87	1,20	1,79	0,79	12,63	1,24
LA (cm)	0,70	0,21	18,99	0,33	0,75	0,18	22,55	0,34	0,56	0,20	18,42	0,32	0,67	0,20	20,03	0,33
RF (LA / LO)	0,57	0,17	15,81	0,27	0,47	0,18	17,63	0,27	0,46	0,16	15,57	0,27	0,50	0,17	16,35	0,27
SF (cm ²)	0,87	0,20	27,81	0,41	1,27	0,13	35,56	0,44	0,94	0,17	28,04	0,39	1,03	0,17	30,63	0,41
LP (cm)	0,09	0,04	12,78	0,06	0,11	0,03	16,35	0,06	0,11	0,03	16,69	0,06	0,10	0,03	15,29	0,06
LNP (cm)	1,70	0,86	11,24	1,24	1,99	0,72	14,72	1,26	1,68	0,78	11,87	1,20	1,79	0,79	12,63	1,24
NS	11,00	6,00	13,36	7,94	12,00	5,00	14,12	7,75	12,00	5,00	15,21	7,75	11,67	5,33	14,22	7,81
ST	16,00	13,00	14,40	6,53	17,00	13,00	14,60	6,44	16,00	12,00	14,52	6,48	16,33	12,67	14,50	8,64

Table 4: Range of Variation Compared to the Average of the Three Sources, Family Number and Percentage of 10 Families (%) for Morphological Characters in Argan Seedlings

Characters	Range of variation	AM	%	AR	%	AB	%	Average for three sources
	< 1,24 cm	1, 2, 6 et 8	40	2, 9 et 10	30	2, 3, 4, 6, 8, 9 et 10	70	
LO	> 1,24 cm	3, 4, 5, 7, 9 et 10	60	1, 3, 4, 5, 6, 7 et 8	70	1, 5 et 7	30	1,24
	< 0,33 cm	6 et 8	20	4, 9 et 10	30	1, 2, 6, 8, 9 et 10	60	
LA	> 0,33 cm	1, 2, 3, 4, 5, 7, 9 et 10	80	1, 2, 3, 5, 6, 7 et 8	70	3, 4, 5 et 7	40	0,33
	< 0,27	4, 5, 6 et 8	40	1, 4, 5, 8, 9 et 10	60	1, 2, 6, 7, 8 et 10	60	
RF	> 0,27	1, 2, 3, 7, 9 et 10	60	2, 3, 6 et 7	40	3, 4, 5 et 9	40	0,27
	< 0,41 cm²	1, 2, 6 et 8	40	2, 4, 9 et 10	40	1, 2, 4, 6, 8, 9 et 10	70	
SF	> 0,41 cm²	3, 4, 5, 7, 9 et 10	60	1, 3, 5, 6, 7 et 8	60	3, 5 et 7	30	0,41
	< 0,06 cm	1, 2, 5, 7, 8, 9 et 10	70	9 et 10	20	2, 6, 9 et 10	40	
LP	> 0,06 cm	3, 4 et 6	30	1, 2, 3, 4, 5, 6, 7 et 8	80	1, 3, 4, 5, 7 et 8	60	0,06
	< 1,24 cm	1, 2, 6 et 8	40	2, 9 et 10	30	2, 3, 4, 6, 8, 9 et 10	70	
LNP	> 1,24 cm	3, 4, 5, 7, 9 et 10	60	1, 3, 4, 5, 6, 7 et 8	70	1, 5 et 7	30	1,24
	< 7,81	2, 5 et 8	30	2, 6, 8, 9 et 10	50	1, 2, 3, 6, 8 et 10	60	
NS	> 7,81	1, 3, 4, 6, 7, 9 et 10	70	1, 3, 4, 5 et 7	50	4, 5, 7, 8 et 9	40	7,81
	< 14,52	2, 4, 5, 7 et 9	50	1, 2, 3, 8 et 9	50	1, 5, 6, 7, 9 et 10	60	
ST	> 14,52	1, 3, 6, 8 et 10	50	4, 5, 6, 7 et 10	50	2, 3, 4 et 8	40	14,52

NOTE: <: Lower; >: Above Average

Table 5: Variance Components and Narrow Sense Heritability (h^2) for Morphological Traits in Argan Seedlings

Sources of variation				Variances			
	LO	LA	RF	SF	LP	LNP	NS ST
Block σ^2_{B}	0,00	0,00019	0,00013	0,00046	0,000001	0,00	0,00575 0.013
Geographic origin σ^2_{Pr}	0,00063	0,0000102	0,00	0,00058	7,16E-07	0,00063	0,0000405 0.00001
Block x geographic origin $\sigma^2_{B \times Pr}$	0,00025	0,00002	0,000047	0,00003	1,16E-07	0,00025	0,00 0.071
Family / geographic origin $\sigma^2_{F/Pr}$	0,00283	0,00078	0,00021	0,00273	6,56E-06	0,00283	0,16517 0.000002
Block x family / geographic origin $\sigma^2_{B \times F/Pr}$	0,00070	0,00035	0,00022	0,00085	0,00001	0,00070	0,06650 0.0000
Block x family / geographic origin x seedling $\sigma^2_{B \times Pl \times F/Pr}$	0,01870	0,00132	0,00092	0,01150	3,96E-05	0,01870	0,68400 0.074
Block x family / geographic origin x seedling x sample (Error) σ^2_{E}	0,00250	0,00640	0,00048	0,00150	0,000042	0,00250	0,34000 0.506
$h^2 = 4\sigma^2 F/Pr / (\sigma^2 F/Pr + \sigma^2 BFPr + \sigma^2 BPlFPr + \sigma^2 E)$	0,46	0,35	0,45	0,66	0,00	0,46	0,53 0.04

Table 6: Correlation Between Traits of Simple Leaves in Argan Seedlings At Nursery Stage

	LO	LA	RF	SF	LP	LNP	NS	ST
LO	1,00							
LA	0,74	1,00						
RF	0,21	0,79	1,00					
SF	0,88	0,96	0,62	1,00				
LP	-0,19	-0,12	-0,04	-0,18	1,00			
LNP	1,00	0,74	0,21	0,88	-0,19	1,00		
NS	0,36	0,65	0,62	0,57	0,08	0,36	1,00	
ST	-0,04	-0,05	-0,09	-0,05	-0,16	-0,04	0,03	1,00

Table 7: Correlation Between Principal Components and Characters of Simple Leaves in Argan Seedlings

Characters	PC1	PC2	PC3
LO	0,87	0,40	0,23
LA	0,97	-0,16	-0,68
RP	0,66	-0,58	-0,27
SF	0,99	0,06	0,03
LP	-0,18	-0,59	0,41
LNP	0,87	0,40	0,23
NS	0,67	-0,48	-0,25
ST	-0,06	0,29	-0,81
Eigenvalues	4,33	1,37	1,09
Percentages explained	54,20	17,10	13,60
Cumulative percentages	54,20	71,30	84,90

NOTE: PC1: First Principal Component, PC2: Second Principal Component, CP3: Third Principal Component

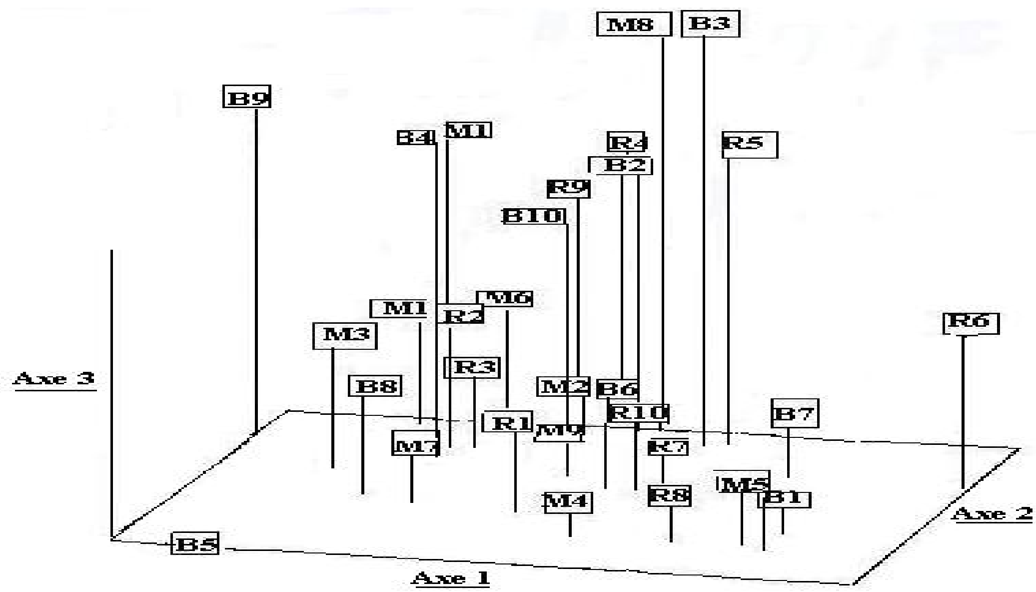

Figure 2: Families from Ait Melloul (M), Argana (R) and Ait Baha (B) Projected on the Space Defined by the three Principal Components Based on Leaf Seedlings Characters

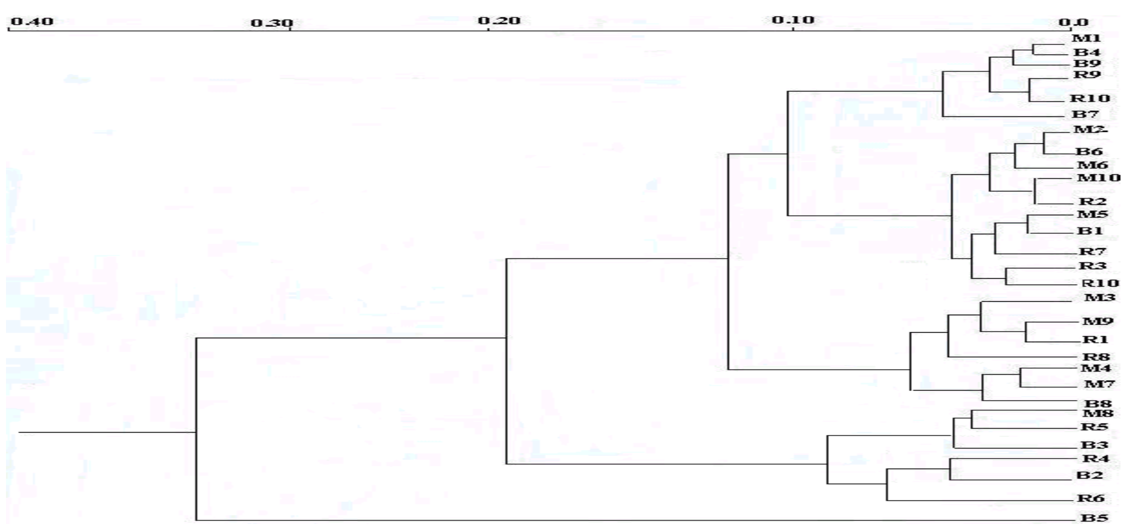

Figure 3: Classification of Individuals from Ait Melloul (M), Argana (R), and Ait Baha (B) for Simple Leaves Traits in Argan Seedlings at Nursery Stage

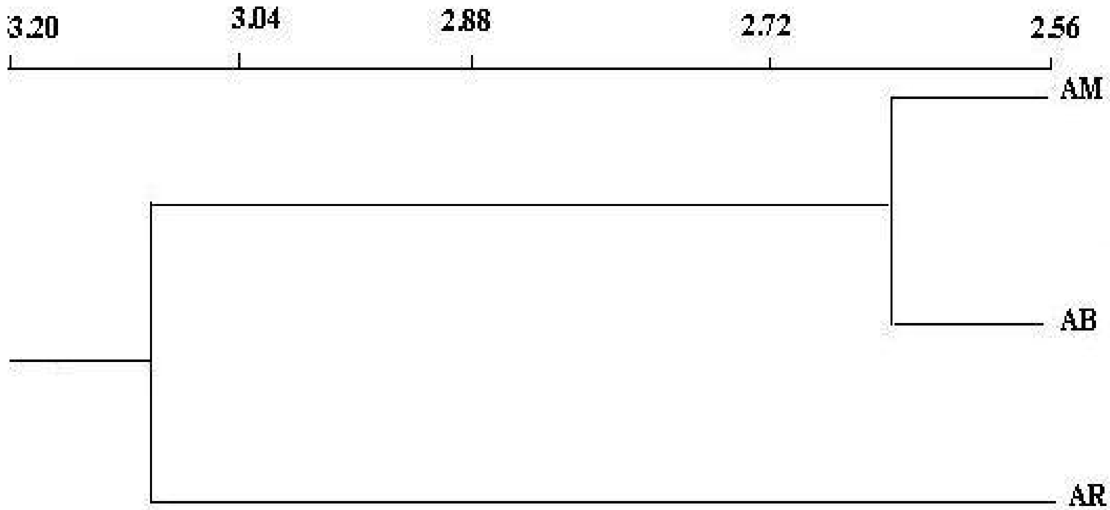

Figure 4: Classification of the Three Localities Ait Melloul (AM), Argana (AR), and Ait Baha (AB) for Simple Leaves Traits in Argan Seedlings at Nursery Stage

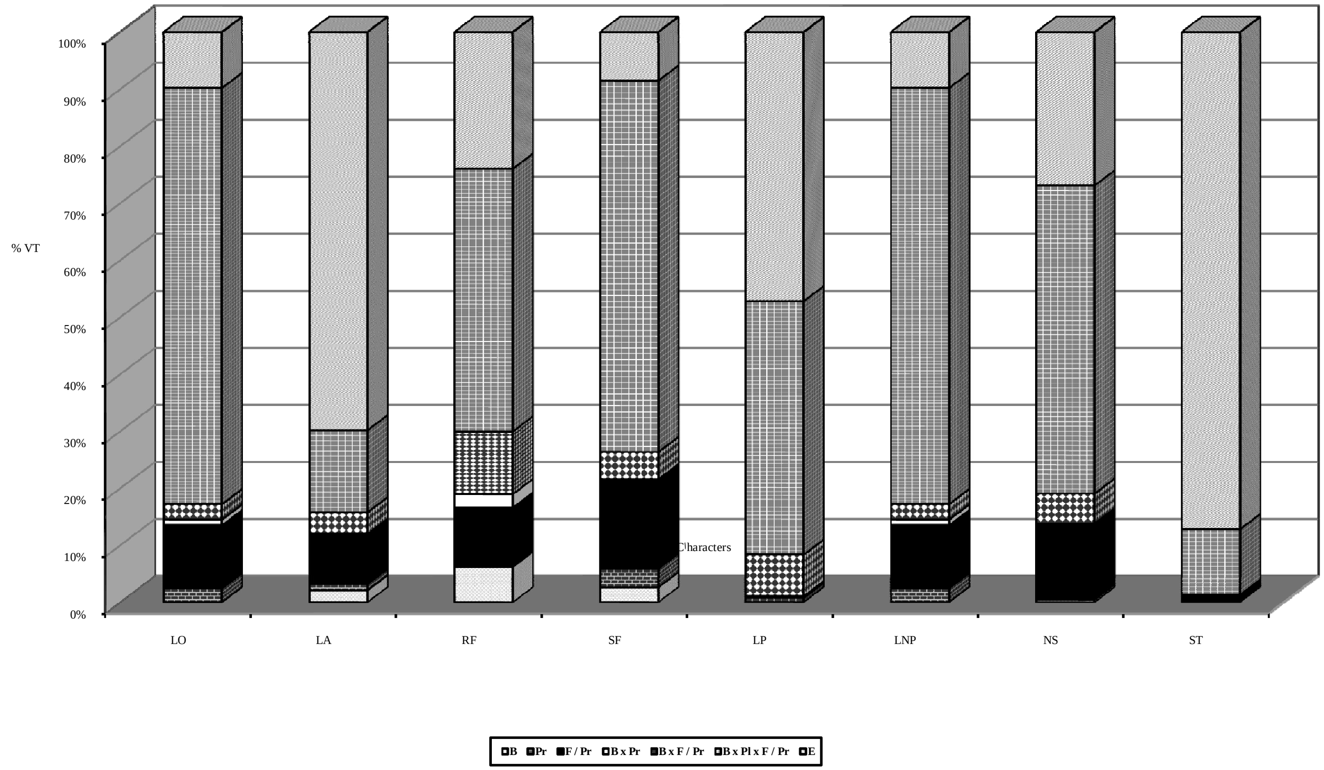

Figure 1: Percentages of the Total Variance for Morphological Characters of Simple Leaves in Argan Seedlings Grown for 12 Months
NOTE: B: Block, Pr: Geographic Origin, F / Pr: Family / Geographic Origin, B x F / Pr: block x Family / Geographic Origin, BxPlxF / Pr: Block x Family / Geographic Origin x Seedling, E: Error