Available online at www.notulaebotanicae.ro

Print ISSN 0255-965X; Electronic 1842-4309

Not. Bot. Hort. Agrobot. Cluj 38 (3) 2010, 293-301

Notulae Botanicae Horti Agrobotanici Cluj-Napoca

Genetic Variability of Argan Tree and Preselection of the Candidate Plus Trees

Naima AIT AABD, Fatima El AYADI, Fouad MSANDA, Abdelhamid EL MOUSADIK

Ibn Zohr University, Faculty of Science, Department of Biology, Laboratory of Biotechnology and Valorisation of Natural Resources, CP 8106, Agadir 80000, Morocco; aitaabdnaima@gmail.com

Abstract

Argan tree productivity shows a wide disparity in space and time, while the degraded forest areas show low growth and unproductive shrubs. Moreover, even if reforestation, currently led by various local actors (Waters and Forests, Agency of Social Development, Cooperatives and Associations of development) experienced a technical improvement, the plants used do not meet any selection criteria. Generally, unknown origin seedlings are used in reforestation and good seedlings are not reproduced. In this context, this study investigates through a choice of pilot sites the characterization *in-situ* of populations and/or argan trees with two selection criteria related to fruit: facility of crushing and oil content. For this purpose, and with the support of local population, the identification of performance trees, prospection and collection of fruits were realized in various sites representing five principal provinces of argan trees area (Essaouira; Taroudante; Agadir Ida Outanane; Chtouka-Ait Baha and Tiznit). Within each provenance, measurements related to 6750 fruits and the morphometric data were subjected to the analysis of the variance, according to the general linear model, where the genotype factor (mother tree) is hierarchical to provenance factor. This study offers preliminary information for the development of a breeding population and allows us to make a first selection of trees, having a clear superiority relating to the characters related to the production of oil and the facility of crushing seeds. At the present moment there is a genetic base large enough to initiate a breeding program.

Key words: argan tree, provenance, oil content, crushing seed, pre-selection

Introduction

In south-west of Morocco, the xerophytes vegetation is dominant and characterises a type of natural plant life. The eco-geography and climatic factors play a significant role in determining the type of vegetation. Natural populations of argan, based only on representative species of the tropical family sapotaceae in Morocco, are widely distributed in arid and semi-arid areas; it plays a great role in the biodiversity of the forest's ecosystem (Msanda *et al.*, 2005). This species include different fruit forms: round, ovoid to the spindle ones, distinguished since 1953 by Chevalier. The dried kernel (almond) of the fruit is used to produce oil. Argan oil is thought to be one of the highest quality vegetable oils, has a high nutritional and dietetic value due to its chemical composition, it is rich in polyunsaturated fatty acid- from 80 to 90%, with two principal fatty acids types: oleic acid type 46 to 55% with an approximate range of linoleic acid 35 to 38% (Charouf and Guillaume, 1999) and unsaponifiable fraction. The oil content depends on the genotype and the environmental conditions; it extends from 50 to 56 g/100 g of kernels (Huyghebaert and Hendricks, 1974; Nerd *et al.*, 1994). Therefore, argan tree (*Argania spinosa* (L.) Skeels) is an important multipurpose oleaginous plant, which plays an immense socio-economical and ecological role; it represents one of the most important production activities and incomes for the indigenous population in the arid regions (Benchakroun and Buttoud, 1989). At the present time, several physical and anthropogenic factors decrease the density and surface of argan ecosystems, so it decreases the biodiversity in natural areas. Due to the continuous increase of genetic erosion, it is necessary to save the situation of this species. The argan tree harbour a high diversity, recorded at different levels (Petit *et al.*, 1998). So, a good understanding of the variation within species is necessary for its domestication, conservation and sustainable management (El Kassaby, 2000). There is, therefore, a strong need to study the genetic variation of argan tree to select the best individuals, with high oil content, to improve its productivity status and also to maintain it in situ and ex situ. According, yet up to now, several studies have been conducted to provide valuable information for the genetic diversity at different levels using different molecular approaches (Bani Aameur and Hilu, 1996; El Mousadik and Petit, 1996a, b; Majaurhat *et al.*, 2008) and phenological studies (Ferradous, 1995; Zahidi, 1997; Bani Aameur and Ferradous, 2001; Benlahbil, 2003). However, variability studies are the prerequisite for genetic improvement of argan tree. Therefore, facing the problem of a strong demand of oil, the seed source testing of this tree is desirable to display the available variation for higher productivity and selecting the very best individuals for breeding programs. Therefore, argan variability can be explained by different environmental and genetic factors (Bani-aameur and Ferradous, 2001). The purpose of this study is to analyse the genetic variability among five provenances by different agro-morphological traits, to determine genetic parameters of some agronomic traits and to pre-select superior genotypes with high oil contents.

Materials and methods

The study area

Five provenances studied cover an area from the Had Dra in Essaouira, Alma in Agadir Ida Outanane, Biougra in Chtouka Ait baha, Aoulouze in Taroudante to Lakhsas in Tiznit. Geographic data base (latitude, longitude, and altitude) were recorded for each accession of argan tree using a global positioning system (Tab. 1). The altitudinal distribution ranges from 109 m in Biougra to 988 m in Lakhsas. The provenances represent different soil conditions and a variety of climatic conditions. They were chosen according to their five main provinces of the argan tree, corresponding to different eco-geographical situations and economic importance.

Tab. 1. Geographic original of argan tree

Origin site	Code	Province	Climate	Topography	Latitude (N)	Longitude (W)	Altitude (m)
Aoulouze	*Ao*	Taroudante	Warm temperate, arid	Smooth slope	30°42´-30°43´	008°06´-008°09´	737-850
Had Dra	*Hd*	Essaouira	Cool temperate , semi-arid	Flat terrain	31°33´-31°35´	009°33´-009°35´	181-226
Alma	*Al*	Agadir	Warm temperate, arid	Smooth slope	30°28´-30°30´	009°33´-009°35´	275-430
Biougra	*Bi*	Chtouka Ait Baha	Warm temperate, arid	Flat terrain	30°14´-30°18´	009°20´-009°21´	109-137
Lakhsas	*La*	Tiznit	Warm temperate, arid	Smooth slope	29°22´	009°43´-009°44´	916-988

Plant materials

A total of 75 argan trees were marked in all five provenances; for each provenance, 15 superior individual trees were chosen according to the investigations with indigenous populations. Random samples of 6750 mature fruits were collected from all provenances corresponding to 90 fruits for each tree.

Tab. 2. Morphological descriptors used in the diversity analysis of argan species

Organ	Trait	Abbreviation	Unit
Tree	Height	HT	m
	Circumference	CiT	m
	Number of trunk	NT	-
	Crown	CrT	m
	Leaf area	LA	cm^2
Fruit	Fruit weight	FW	g
Seed	Seed weight	SW	g
	Seed length	SL	mm
	Seed width	SW	mm
	Hull thickness	HT	mm
	Carpel number	CN	-
Almond	Almond number	AN	-
	Almond weight	AW	g
	Almond length	AL	mm
	Almond width	AWi	mm
	Almond weight/seed weight ratio	AW/SW	-
	Almond weight for 90 seed	AW-90S	g
	Oil content	OC	%
	Oil volume	OV	ml

Evaluation trials

Diversity of agro-morphological characters was measured using quantitative and qualitative characters as described in Tab. 2; it was performed on tree, fruit and seed traits to each tree preselected. The oil content character was estimated by Soxhlet method using two repetitions for each tree.

Statistical analyses

STATISTICA V.6 software was used to determine the minimum, the maximum, coefficient of variation and the range for different parameters, to analyse the data and to evaluate agromorphologically diversity inter- and intra-provenance.

Genetic parameter estimates

The statistical analysis was based on the following linear model: $X_{ijk}=\mu+P_i+A/P_{ij}+e_{ijk}$, where Xijk is the value of the studied variable which is the sum of four components defined as follows: μ = the overall mean, Pi = the effect of the ith provenance, A/Pij = effect of the jth tree within the ith provenance (random) and eijk = the residual term. Variance components σ^2_p (phenotypic variance) and σ^2_g (genotypic variance) were estimated from the mean squares in the analysis of variance (Panse and Sukhatme, 1976; Falconer and Mackay, 1996), Phenotypic (PCV) and genotypic (GCV) coefficients of variation were calculated as: $CV= (\sqrt{\sigma^2}/\mu)*100$, where $\sqrt{\sigma^2}$ correspond the phenotypic and genotypic standard deviations, and μ is the global mean. Heritability in the broad sense (h^2) and genetic advance (GA) was estimated by (Johnson *et al.,* 1955), where $h^2= \sigma^2_g/\sigma^2_p$ and GA (as% of the mean) = $(GA/\mu)*100$ was calculated with the intensity of selection (i) assuming selection of the superior 20% of the genotypes using the formula $GA=i\sqrt{\sigma^2}ph^2$. Phenotypic and genetic correlations coefficients among the characters studied were calculated from the analysis of covariance using the model corresponding to the analysis of variance following (Kwon and Torrie, 1964).

Results

Provenance analysis

Descriptive analysis of 21 agro-morphometric traits of 75 individual trees belonging to the five geographical different provenances is presented in Tab. 3. In general, the majority of morphological traits exhibited a wide range of variation, expressed by a coefficient of variation ranging from 5.11% to 83.51%. Three trees of Alma provenance (*Al-6V, Al-15V, Al-2V*) show minimal value for the majority of traits. Maximum value for fruit weight (7.36 g), seed weight (4.14 g) and almond weight (0.39 g) were recorded at *La-9V*. The oil content varies from 39.19% in *Al-2V* to 57.92% in *Hd-3V* with a maximum oil volume at 6.59 ml/10 g of almond.

The comparison of means (Tab. 4) reveals that provenance *Bi* showed the highest mean values for the crown diameter of tree (10.59 m), leaf area (64.94 cm^2), fruit weight (4.17g), seed weight (2.61g), seed length (22.68 mm), seed width (14.77 mm), hull thickness (2.39 mm), almond weight (0.28 g), almond length (17.23 mm), almond width (9.11 mm) and almonds weight of 90 seeds and mean value lowest for almond weight/seed weight ratio (0.11). Provenance *La* showed the highest mean value for the oil yield (53.76%) which corresponds to 6.06 ml/10 g of almond, this provenance shares the highest mean value of almond weight/seed weight ratio (0.13) with *Ao* and *Hd* provenances, which are classified in the same group. Also, three provenances: *Ao, Hd* and *Bi* showed the same value of the oil content and almond weight/seed weight ratio trait. However, a high difference between these provenances and provenance *Al* was found for all traits. The analysis of variance according to Steel *et al.* (1997) shows a non-significant variation (P<0.05) among the argan genotypes for tree dimensions: plant height, circumference, number of trunk, crown tree and leaf area. However,

Tab. 3. Descriptive statistics (ranges, mean value, standard errors of mean-SE and coefficient of variation-CV) for each morphological trait measured in five provenances of argan trees

Traits	Minimum		Maximum		Mean	SE	CV
	Value	Tree	Value	Tree			
HT	3.00	*La-6V*	11.00	*Hd-9V*	6.66	1.56	23.48
CiT	1.00	*Ao-9V*	5.80	*Al-4V*	2.66	1.29	48.71
NT	1.00	*	12.00	*Al-1V*	2.12	1.77	**83.51**
CrT	4.40	*Bi-1V*	20.80	*La-14V*	9.82	3.24	33.00
LA	12.16	*La-5V*	115.90	*Bi-15V*	47.25	2.87	6.08
FW	1.09	***Al-6V***	7.36	***La-9V***	3.31	1.17	35.51
SW	0.50	***Al-6V***	4.14	***La-9V***	1.90	0.74	38.77
SL	10.67	***Al-6V***	26.55	*Bi-2V*	19.09	3.65	19.13
SW	8.93	***Al-6V***	18.52	***La-9V***	13.26	1.68	12.71
HT	1.40	***Al-6V***	3.29	***Bi-7V***	2.08	0.37	17.72
CN	1.50	*Ao-10V*	3.04	***Bi-7V***	2.25	0.27	11.90
AN	0.94	***Al-2V***	1.68	*Hd-13V*	1.12	0.12	10.83
AW	0.06	***Al-15V***	0.39	***La-9V***	0.23	0.07	32.41
AL	6.80	***Al-15V***	21.58	*Bi-15V*	14.71	3.05	20.72
AWi	4.98	***Al-15V***	11.59	***La-9V***	8.24	1.20	14.62
AW/SW	0.06	*Bi-4V*	0.18	***Al-6V***	0.12	0.02	18.79
AW-90S	5.10	***Al-15V***	36.56	*La-13V*	20.75	6.48	31.21
OC	39.19	***Al-2V***	57.92	*Hd-3V*	52.29	2.90	5.54
OV	4.85	***Al-2V***	6.59	*Hd-3V*	5.90	0.30	**5.11**

* Other trees have this value

Tab. 4. Comparison of the mean values and analysis of variance for the morphological traits over five provenances studied

Traits	*Ao*	*Hd*	*Al*	*Bi*	*La*	*F*	p
HT	**6.97^{a}**	6.77^{a}	6.33^{a}	6.41^{a}	6.83^{a}	0.45	ns
CiT	**3.04^{b}**	1.96^{a}	2.54^{ab}	2.85^{ab}	2.90^{ab}	1.74	ns
NT	2.00^{a}	1.53^{a}	**2.93^{a}**	2.40^{a}	1.73^{a}	1.54	ns
CrT	8.61^{a}	10.21^{a}	9.49^{a}	**10.59^{a}**	10.21^{a}	0.87	ns
LA	45.76^{ab}	56.22^{bc}	32.91^{a}	**64.94^{c}**	36.42^{a}	6.75	ns
FW	3.08^{a}	2.94^{a}	2.25^{c}	**4.17^{b}**	4.09^{b}	11.23	***
SW	1.71^{ab}	1.73a^{b}	1.30^{a}	**2.61^{c}**	2.15^{b}	10.33	***
SL	18.86^{a}	19.03^{a}	15.70^{b}	**22.68^{c}**	19.17^{a}	10.33	***
SW	12.63^{a}	12.68^{a}	12.23^{a}	**14.77^{b}**	13.97^{b}	8.57	***
HT	1.91^{a}	1.95^{a}	1.97^{a}	**2.39^{b}**	2.16^{ab}	5.71	***
CN	2.17^{b}	2.27^{a}	2.27^{a}	2.20^{a}	**2.35^{c}**	1.02	***
AN	1.07^{a}	**1.20^{b}**	1.16^{ab}	1.09^{a}	1.10^{a}	3.18	***
AW	0.21^{a}	0.23^{a}	0.16^{c}	**0.28^{b}**	0.26^{ab}	8.84	***
AL	14.89^{a}	15.11^{a}	11.43^{b}	**17.23^{c}**	14.87^{a}	10.63	***
AWi	8.09^{a}	8.01^{a}	7.08^{c}	**9.11^{b}**	8.90^{b}	10.16	***
AW/SW	**0.13^{a}**	**0.13^{a}**	0.12^{ab}	0.11^{b}	**0.13^{a}**	2.34	***
AW-90S	19.63^{b}	20.72^{ab}	14.45^{c}	**24.85^{a}**	24.10^{a}	8.75	***
OC	52.72^{a}	52.05^{ab}	50.17^{b}	52.74^{a}	**53.76^{a}**	3.61	***

*** Significant at p< 0.001; ns = not significant

Tab. 5. Mean square values from ANOVA analysis (GLM) for agro-morphometrical data in five locations

Traits	Provenance (df=4)	Genotype (df=74)	Genotype (Provenance) (df=70)
FW	865.96**	123.17**	80.72**
SW	304.45**	47.24**	32.54**
SL	7231.21**	1137.46**	789.25**
SW	1435.13**	251.76**	184.14**
HT	45.79**	11.77**	9.83**
CN	6.26**	6.51**	6.53**
AN	3.64**	1.33**	1.20**
AW	2.89**	0.48**	0.34**
AL	462.45**	810.27**	550.14**
AWi	885.80**	128.90**	85.65**
AW/SW	0.09**	0.05**	0.04**
AW-90S	1.22**	0.62**	0.59**
OC	26.30**	8.9**	7.9**

df = degrees of freedom; ** significant at p ≤ 0.01

highly significant differences ($p < 0.001$) were revealed between provenance and trees for the rest characters.

Evaluation of this difference inter- and intra- trees/provenance is illustrated in Tab. 5. An important genetic variation among the natural populations is often considered. High significant (P<0.01, GLM) variation was recorded within and between trees and provenance for all characters. Moreover, the factors of genotype, provenance and genotype in provenance indicate the high significant difference for all the characters (Tab. 5).

Genetic parameters

To compare the variation among various traits, estimates of variance components (σ^2_p, σ^2_g), phenotypic (PCV) and genotypic coefficient of variability (GCV), broad sense heritability (h^2) and genetic advance (GA) as a percentage of mean are given in Tab. 6.

Phenotypic coefficient of variability (PCV) is very random, ranged from 1.95 (AW-90S) to 47.64% (AW). The genotypic coefficient of variation (GCV) showed similar trends as (PCV) and ranged between 0.90% for (AW-90S) and 31.57% for seed weight. Heritability estimates in broad sense were higher than 45% under study, which reflected the predominance of heritable variation for all the traits. The heritability in the broad sense for all characters is ranging between 8.02 % for a number of almonds per seed and 93.28 % for oil content. The highest heritability ($h^2 > 40\%$) as recorded for oil content closely followed by fruit weight, seed weight, seed length, almond length, seed width and hull thickness. Among them, the heritability of number of the carpel, almond weight, almond width, almond weight/seed weight ratio and almonds weight of 90 seeds, was relatively higher ($40\% > h^2 > 20\%$). Heritability estimates for number of almonds were lower ($h^2 < 20\%$) than all traits.

Genetic advance (GA) varied from 0.13% for almond weight of 90 seeds to 7.95% for seed weight (Tab. 6). Though, high heritability for the character coupled with high genetic advance was detected. AW/SW ratio trait presents the lowest genetic advance. The character, fruit weight, seed weight, seed length, seed width and oil content exhibited highest genetic advance.

Tab. 6. Estimation of genetic parameters for fruit, seed, almond and oil content traits

Traits	σ^2_p	σ^2_g	h^2 (%)	PCV (%)	GCV (%)	GA	GA (%)
FW	1.39	0.89	64.15	35.66	28.56	0.24	7.32
SW	0.58	0.36	61.99	40.09	**31.57**	0.15	7.95
SL	**11.33**	**8.74**	77.13	17.64	15.49	**0.83**	4.35
SW	3.44	2.03	59.07	13.99	10.75	0.35	2.64
HT	0.24	0.11	45.20	23.52	15.82	0.07	3.40
CN	0.23	0.07	30.75	21.31	11.82	0.05	2.10
AN	0.15	0.01	**8.02**	34.22	9.69	0.01	0.88
AW	0.01	0.00	31.65	**47.64**	26.80	0.01	4.82
AL	11.02	6.06	54.98	22.57	16.74	0.58	3.97
AWi	2.74	0.93	34.00	20.10	11.72	0.18	2.19
AW/SW	**0.00**	**0.00**	25.93	35.15	17.90	**0.00**	2.92
AW-90S	0.16	0.04	21.39	**1.95**	**0.90**	0.03	**0.13**
OC	6.56	6.12	**93.28**	4.90	4.73	0.76	1.46

Phenotypic variances (σ^2p); genotypic variances (σ^2g); (h^2) broad-sense heritability; (PCV) phenotypic coefficient of variation, (GCV) genotypic coefficient of variation. (GA) genetic advance and GA as percent (% of mean)

Correlation coefficients of various agro-morphometrics traits of argan trees with oil contents

Genotypic and phenotypic correlation coefficients between various characters are shown in Tab. 7. The phenotypic and genetic correlations revealed that tree dimension, hull thickness, number of carpel, number of almond per seed, are not correlated to the oil content. Fruit weight, seed weight, almond weight, seed length, seed width and AW-90S are positively correlated with oil content. Contrary, fruit weight, seed weight, length and width seed and hull thickness are negatively correlated and stronger with AW/SW ratio trait. However, Hull thickness character shows an unexpected result concerning its correlation with AW/SW ratio trait. Also, almond weight and the number of almond per seed are positively correlated to this trait. The magnitude of correlation coefficient at genotypic level was higher than their corresponding phenotypic coefficient of correlations.

Selection the candidate plus trees (CPTs) of argan tree from different locations

The trees which are the subject of this study are candidate plus trees, according to the users of the autochthons populations of argan and similarly, in spite of the dryness which dominated since 1997 up to 2008, they are borne fruit. The breaking of the argan seeds constitutes a boring

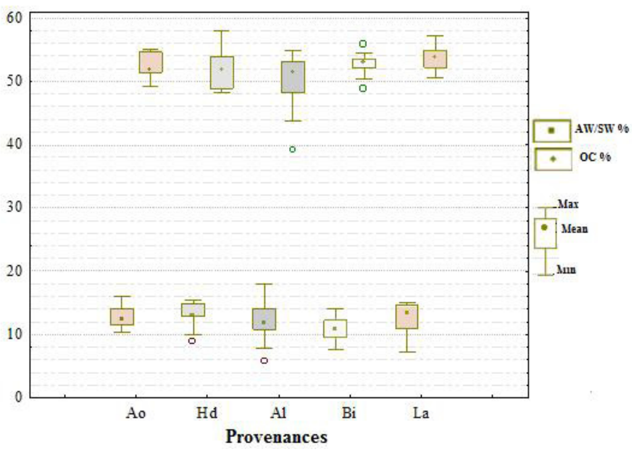

Fig. 1. Distribution of the mean values of two selection criteria (AW/SW (%) and OC (%)) of the best trees in five agro-ecological zones study

Tab. 7. Genotypic (G) and Phenotypic (P) correlation coefficient between morphological traits and oil contents in argan tree

Variable	Correlation	FW	SW	SL	SW	HT	CN	AN	AW	AL	AWi	AW/SW	AW-90S
SW	G	0.89***											
	P	0.89***											
SL	G	0.68***	0.69***										
	P	0.58***	0.69***										
SW	G	0.78***	0.87***	0.58***									
	P	0.79***	0.87***	0.58***									
HT	G	0.75***	0.77***	0.58***	0.73***								
	P	0.77***	0.79***	0.55***	0.75***								
CN	G	0.10	0.12	-0.14	0.13	0.07							
	P	0.09	0.11	-0.15	0.13	0.07							
AN	G	-0.06	-0.01	-0.18	0.07	-0.21	0.21*						
	P	-0.13	-0.09	-0.26	0.01	-0.26	0.19*						
AW	G	0.63***	0.72***	0.60***	0.70***	0.38***	0.01	0.27**					
	P	0.63***	0.72***	0.61***	0.70***	0.40***	-0.02	0.17					
AL	G	0.18*	0.19*	0.26**	0.15	0.13	-0.06	-0.04	0.20*				
	P	0.20*	0.20*	0.28***	0.16	0.15	-0.07	-0.08	0.22**				
Awi	G	0.57***	0.68***	0.44***	0.72***	0.42***	-0.04	0.09	0.81***	0.17***			
	P	0.58***	0.69***	0.45***	0.74***	0.45***	-0.04	0.01	0.82***	0.17***			
AW/ SW	G	-0.40*	-0.40*	-0.27*	-0.41*	-0.58*	-0.12	0.40***	0.20**	-0.02	0.07		
	P	-0.43*	-0.43*	-0.29*	-0.44*	-0.61*	-0.14	0.39***	0.17*	-0.03	0.03		
AW- 90S	G	-0.30	-0.31	-0.21	-0.32	-0.51	-0.08	0.47***	0.23*	0.01	0.12	0.86***	
	P	-0.53	-0.54	-0.37	-0.56	-0.76	-0.17	0.50***	0.21*	-0.04	0.04	0.21	
OC	G	0.21**	0.17**	0.21**	0.05**	0.43	-0.08	-0.02	0.26**	0.08	0.14	0.22	0.14*
	P	0.22***	0.18**	0.22**	0.05**	0.44	-0.08	-0.03	0.28***	0.09	0.14	0.21	0.27***

*** Significant at 0.1% level; ** significant at 1% level; * significant at 5% level

stage for the production of oil, and for that, the selection lookes for the most productive trees and easy to break seeds, which necessarily point the need for such a program to increase and improve the oil productivity. These characters are suggested as promising traits for selection of elite genotype suitable for this tree breeding programme. Since then, significant contributions have been made in selection of high yielding plants or plus trees.

The comparison of means (Fig. 1) for these two traits between provenances selected reveals that provenances *Hd, Ao, La* and *Bi* showed the highest mean values for oil content. However, provenance *Al* showed the lowest mean values for this trait. Three provenances *Hd, Ao* and *La* showed the highest mean values for AW/SW ratio contrary to *Bi* and *Al* provenance.

Been observed significant variation between the provenances and between the genotypes, in two parameters of agro-morphometrical importance: oil content and AW/SW ratio. Significant differences between mean values of each tree genotype were compared using the Duncan multiple range test (5%) and regrouping in homogenises groups (Fig. 2).

For all genotypes, oil content expressed in volume range from 4.85 to 6.59 ml/ 10 g of almond and AW/SW ratio range from 0.06 (very hard crack seed) to 0.18 (very easy crack seed).

For this, the superior argan trees were selected within each provenance having better oil content and AW/SW ratio, over mean of their provenance (Fig. 2).

The total of these trees changes from one provenance to another and from one selection criteria to another. For 15 superior individuals for each provenance and for oil content, 9 trees valuable for selection are selected in provenances *Al, Bi* and *La* and 7 trees are selected in provenance *Ao* and *Hd*. However, for easy to crack seed trait, all provenances had the same effective 6/15, contrarily provenance *Hd* containing 7 superior tree in all trees studied. Though, if one associates these two traits, the selection becomes more severe to select the genotypes apt to our objective, which has 2 genotypes for provenance *Ao*, 4 genotypes for *Al, Bi, La* provenances and 5 genotypes for *Hd*.

Discussion

The analysis of variance according to general linear model (GLM) revealed highly significant differences (P<0.01) among the argan genotypes for all characters studied.

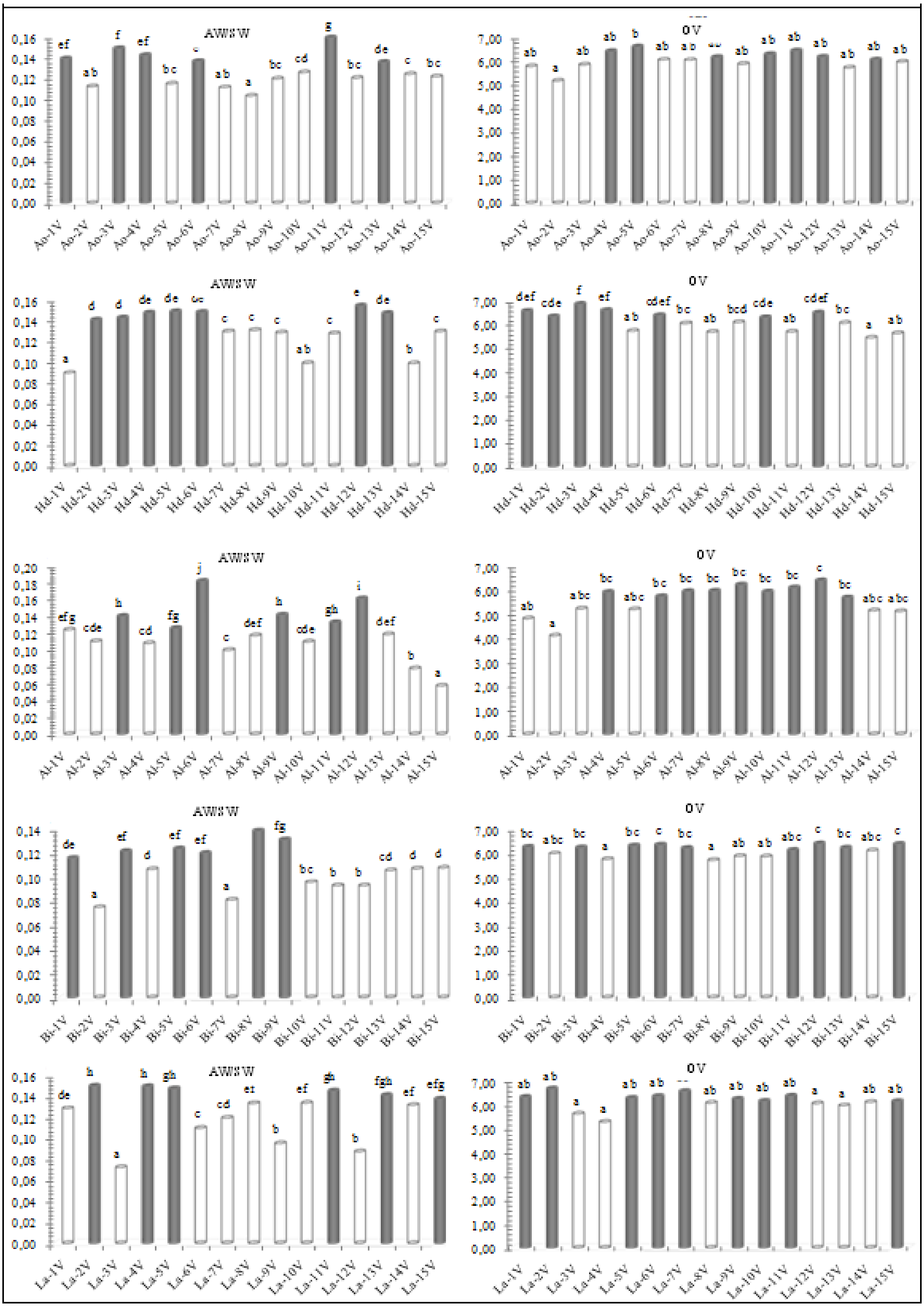

Fig. 2. Classification the superior genotypes with high two selection criteria (oil content expressed in volume (ml) and WA/SW ratio traits) for all provenance studied, using Duncan at 5%, (grey columns indicate trees having exceeded significantly mean of the concerned provenance)

Results obtained for the qualitative and quantitative characters between argan genotypes and between provenances indicate that an important genetic variation exists between individual accessions within each provenance. Similar studies based on the description of the provenances using morphological traits were made on shea tree, *Vitellaria paradoxa* (Sanou *et al.*, 2006), and very important spotacaea species as *Argania spinosa* in Morocco. When the variance between populations is considered, climatic and soil effects can be markedly different between locations and the variance between populations often strongly confound the environmental and the genetic variance (Sanou *et al.*, 2006).

Highly significant differences between provenances and genotypes for the majority of morphological traits ($P<0.01$), was observed, except the trees traits. Fruit traits shows higher levels of coefficient of variance (CV), indicating a high variation between trees, this can be explained by the result of two combined influences-climate conditions and eco-geographical distribution. In spite of the observed variation, the provenance *Hd, Ao, La* and *Bi* showed the best performance for all traits, contrary to the provenance *Al*, because this provenance showed the most sensitive to dryness factor dominated during our study. For that, arid climate dominate in four provenances (*Al, Bi, Ao* and *La*), and semi arid area for provenance *Hd*, apart from these environmental factors, there are two geographic situation varied to the arid rocky mountains for provenance *La* and *Ao* and plain region for provenance *Bi, Al* and *Hd*. The variance related to the locality effect is generally lowest at argan, since it has a great adaptive plasticity to the geographical area (Bani Aameur and Ferradous, 2001). The study of seed morphological characters of the natural populations is often considered to be useful in the study of the genetic variability (Kaushik *et al.*, 2007). Uni and multivariate procedures based on morphologic and agronomic traits have been used in the assessment of genetic diversity and performances in other species such as *Acacia tortilis* and *Acacia raddiana* in Tunisia (El Ferchichi *et al.*, 2009), *Pinus roxburghii* Sarg. (Mukherjee *et al.,* 2004), *Pinus sylvestris* L. (Rweyongeza *et al.,* 2002), *Triticum turgidum* var. *Durum* (Maniee *et al.*, 2009) and sunflower (*Helianthus annus* L.) (Ekin *et al.*, 2005). This research manages to simulate the genotypic effect and the environmental effect on the phenotypical values of an individual under various climates. This variability in tree characters, pod and seed can be exploited for the selection of desirable plant genotypes for breeding programme. The decomposition of variance recorded between argan genotypes for all traits, and the relationship of oil contents in five provenances studied can be exploit to evaluate the variance related to differences between the genotypes (σ^2 inter-provenance) and the variance related to the geographic area (σ^2 geographic). Little difference between phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) and high estimates of heritability (broad sense) for fruit and seed weight, seed and almond length, seed breadth and oil content characters under study, revealed the heritable nature of present variability. High estimates of heritability (>54%) suggested that these traits play an important role in predicting the selection of best individual. A higher heritability (broad sense) estimated for oil content (93%) indicates the lowest environmental effect; a similar result has been observed on another species such as *Pongamia pinnata* (L) which $h^2oc = 100\%$, (Kaushik *et al.*, 2007), *Jatropha curcas* L. $h^2oc = 99\%$ (Kaushik *et al.*, 2007) and sunflower, $h^2oc = 71\%$ (Mudassar *et al.*, 2009). The number of almond per seed showed minimum magnitude of broad sense heritability and moderate value of genetic advance, which advocated that this character might be influenced by pollination. Heritability estimate has an important place in tree improvement programme, while it provides an index of the relative role of heredity and environment in the expression of various traits (Johnson *et al.*, 1955; Dorman, 1976); it is also indicated that the importance of this estimation is useful when accompanied by estimation of genetic advance for future improvement through selection. Fruit weight, seed weight, seed size, almond length and oil content showed maximum magnitude of broad sense heritability coupled with high genetic advance; this was an indication of the involvement of the genetic and additive effects in the inheritance of these characters (Mudassar *et al.*, 2009), advocate that this character might be improved through selection. Therefore, these characters are good indicators for such program of selection and improvement of the argan tree, However, this study investigates two selection criteria in advance of good performing trees in relation to the oil contents; these two criteria are oil content and easy crushing seeds, because these traits are useful to guarantee continuity and a sustainable development for this species. The impact of various quantitative and qualitative traits on oil contents and facility to crush seeds is made by the study of correlation. According to Falconer, 1989, the study of this correlation is required to obtain the response of various traits to the characters interesting selection. Genotypic and phenotypic correlation coefficients between various characters under study revealed that the magnitude of correlation coefficient at genotypic level was higher than their corresponding phenotypic coefficient of correlations. This clearly indicated the genotypic association among the characters (Kaushik *et al.*, 2007). Oil content ranged from 39.19% to 57.92%, with similar results observed on *Azadirachta indica* in five provenances in India (Kaura *et al.*, 1998). This character showed significant positive correlation with fruit, seed and almond weight, seed and almond size and almond weight of 90 seeds ($P<0.05$). However, there was no correlation between facility to crushing seed traits and oil content. A highly significant and negative correlation was found between this traits and fruit weight, seed weight, seed size, almond size and hull thickness. Through, positive correlations with almond weight were detected. Facility or difficulty to crushing seeds does not have any relation with the oil content, due to morphological aspect of trees (size, port, ramification, etc) (Nouaïm *et al.*, 2007). The response to crushing studied showed that the trees with seeds easy to break present a hull thickness and AW/SW ratio statistically very low, contrary to the trees with seed difficult to break; these results are similar to the results found by Nouaïm *et al.*, 2007. Selection of good performing trees (candidate tree plus) having more oil content was based on these characters: best oil yield contents and facility of breaking the seeds. Number of the selected trees becomes more rigorous because of the absence of interdependence between these two characters interesting selection. However, the effect of this selection changes from provenance to another, where the frequency of the trees selected and repented to our objective is 7% in provenance Ao, 27% in provenances *La, Bi* and *Al* respectively, and 33% at the *Hd* provenance. Hence, provenance Al is less classified to other provenances, but having the good genotypes will be selected. This may be justified by the high mean value of these two traits of selection were explained by a great plasticity adapted to the aridity of this species.

Conclusions

Significant variations in characters studied were detected both at within and between provenance levels. Diversity analysis of the argan genotypes studied using the agromorphometrical approach allowed for selection of genotypes adapted to two selection criteria. Furthermore, the higher amount of heritability in broad sense coupled with considerable genetic advance for oil contents, fruit and seed weight, seed size and almond length indicated the additive genetic effects in the heritage of these characters. High heritability 93% of oil content can be considered as a good genetic marker for early selection of seed sources. Positive and significant correlation of oil contents with fruit weight, seed weight and seed size report that these traits could be useful criteria of selection for the oil yield under different environmental conditions. Moreover, this result has important practical implications for genetic management of resource and for future breeding activities of improvement programmes of argan tree.

References

Bani-Aameur, F. and A. Ferradous (2001). Fruits and stone variability in three argan (*Argania spinosa* (L.) Skeels) populations. Forest Genetics 8:39-45.

Bani-aameur, F. and W. Hilu (1996). Use of DNA from leaves for RAPD analysis. Conference on Plant Taxonomy, Barcelone 19-22 September (Abstract).

Benchekroun, F. and G. Buttoud (1989). L'arganeraie dans l'économie rurale du sud ouest marocain. Forêt Méditerranéenne (2):127-136.

Benlahbil, S. (2003). Pollinisation naturelle et artificielle de l'arganier (*Argania spinosa* (L.) Skeels). Thèse de Doctorat En-Sciences, Faculté des Sciences, Université Ibnou Zohr. Agadir.

Charrouf, Z. and D. Guillaume (1999). Ethnoeconomical, ethnomedical, and phytochemical study of *Argania spinosa* (L.)Skeels. Journal of Ethnopharmacology 67:7-14.

Chevalier, A. (1953). L'argan, les Marmulanos et les Noyers, arbres d'avenir en Afrique du Nord, en Macaronésie et dans les regions semi-désertiques du globe si on les protège et si on les améliore. Rev. Int Bot. Appl. Agric. Trop. 363-364.

Dorman, K. W. (1976). The genetics and biodiversity of southern Pines agriculture handbook, 471 pp. Washington, D.C: USDA, US.

Ekin, Z., M. Tunçtürk and I. Yilmaz (2005). Evaluation of seed, oil yields and yield properties of different sunflower (*Helianthus annus* L.) hybrid varieties in Van, Turkey. Pakistan Journal of Biological Sciences 8(5):683-686.

El Ferchichi, H. O., D. J. Walker, M. L. Khouja and E. Correal (2009). Diversity analysis of *Acacia tortilis* (Forsk.) Hayne ssp. *raddiana* (Savi) Brenan (*Mimosaceae*) using phenotypic traits, chromosome counting and DNA content approaches. Genet Resour Crop Evol 56(7):1001-1010

El Kassaby, Y. (2000). Effect of forest tree domestication on gene pools, 197-213 pp. In: Young A., D. Boshier and T. Boyle (Eds.). Forest Conservation Genetics, Principles and Practise. CSIRO Publishing and CABI Publishing.

El Mousadik, A. and R. J. Petit (1996a). High level of genetic differentiation for allelic richness among population of argan tree (*Argania spinosa* (L.)Skeels) endemic to Morocco. Theor. Appl. Genet. 92:832-839.

El Mousadik, A. and R. J. Petit (1996b). Chloroplast DNA phylogeography of argan tree of Morocco. Mol. Ecol. 5:547-555.

Falconer, D. S. (1989). Introduction to quantitative genetics, 2nd Edition. Longman New York, USA.

Falconer, D. S. and T. F. C. Mackay (1996). Introduction to quantitative genetics. 4th Edition. Pearson Education Ltd., Essex, England.

Ferradous, A. (1995). Diversité génétique de quelques caractères morphologiques du fruit et de la graine d'arganier (*Argania spinosa*. (Skeels)). Thèse présentée pour l'obtention du diplôme des études supérieures de 3th cycle (D.E.S). Université Ibn Zohr, Faculté des Sciences Agadir.

Huyghebaert, A. and H. Hendrick (1974). Quelques aspects chimiques, physiques et technologiques de l'huile d'argan. Oléagineux 10:29-31.

Johnson, H. W., H. F. Robinson and R. E. Comstock (1955). Estimates of genetic and environmental variability in soybeans. Agron J 47:314-318.

Kaura, S. K., S. K. Gupta and J. B. Chowdhury (1998). Morphology and oil content variation in seeds of *Azadirachta indica* A. Juss (neem) from northern and western provenances of India. Plant Foods and Human Nutrition 52: 293-8.

Kaushik, N., K. Kumar, S. Kumar, N. Kaushik, and S. Roy (2007). Genetic variability and divergence studies in seed traits and oil content of Jatropha (*Jatropha curcas* L.) accessions. Biomass and Bioenergy 31:497-502.

Kaushik, N., S. Kumar, K. Kumar, R. S. Beniwal, N.Kaushik and S. Roy (2007). Genetic variability and association studies in pod and seed traits of *Pongamia pinnata* (L.) Pierre in Haryana, India. Genet Resour Crop Evol 54:1827-1832.

Kown, S. and J. Torrie (1964). Heritability and interrelationship among traits of two soybean populations. Crop Sci 4:196-198.

Majourhat, K., Y. Jabbar, A. Hafidi, G. P. and Martínez (2008). Molecular characterization and genetic relationships among most common identified morphotypes of critically endangered rare Moroccan species *Argania spinosa (Sapotaceae)* using RAPD and SSR markers. Ann. For. Sci. 65(2008)805.

Maniee, M., D. Kahrizi and R. Mohammadi (2009). Genetic variability of some morpho-physiological traits in Durum wheat (*Triticum turgidum* var. Durum). J of App. Sci. 9(7): 1383-1387.

Msanda, F., A. El Aboudi and J. P. Peltier (2005). Biodiversité et biogéographie de l'arganeraie marocaine. Cahiers Agricultures 14(4):357-364.

Mudassar, I., A. M. Amjad, A. Amjad, M. Zulkiffal, M. Zeeshan, and H. A. Sadaqat (2009). Genetic behavior and impact of various quantitative traits on oil contents in sunflower under waters stress conditions at productive phase. Plant Omics Journal 2(2):70-77.

Mukherjee, S. R., R. C. Thapliyal and S. S. Phartyal (2004). Seed source variation in cone, seed and seedling characteristic across the natural distribution of Himalayan low level pine *Pinus roxburghii* Sarg. Silvae Genetica 54(2):76-80.

Nerd, A., Eteshola, E., Boroway, and Misrahi, Y. (1994). Growth and oil production of argan in the desert of Israel. Ind. Crops Prod. 2:89-95.

Nouaim, R., Echairi, A., Kaaya, M. and Chaussod, R. (2007). Contribution à la domestication de l'arganier pour la production d'huile. Cahiers Agricultures 16(3):199-204.

Panse, V. G. and P. V. Sukhatme (1976). Statistical methods for agricultural workers, New Delhi.

Petit, R. J., A. El Mousadik and O. Pons (1998). Identifying populations for conservation on the basis of genetic markers. Conservation Biology 12:844-55

Rweyongeza, D. M., F. C. Yeh, B. P. Dancik and N. K. Dhir (2002). Genetic variation in height, branch and needle lengths of *Pinus sylvestris* L. from Siberia tested in Alberta, Canada. Silvae Genetica 52:52-60.

Sanou, H., H. Picard, N. Lovett, P.N. Dembélé, M. Korbo, A. D. Diarisso and J. M. Bouvet (2006). Phenotypic variation of agromorphological traits of the shea tree, *Vitellaria paradoxa* C.F. Gaertn., in Mali. Genetic Resources and Crop Evolution 53:145-161.

Steel, R., J. Torrie and D. Dicky (1997). Principles and Procedures of Statistics; a biometrical Approach. 3rd Ed. W.C.B/ McGraw-Hill, New York.

Zahidi, A. (1997). Phénologie, typologie et variabilité génétique des caractères de la ramification et de la foliation de l'arganier (*Argania spinosa* (L.)Skeels). D.E.S. Université Ibnou Zohr, Agadir.