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Morphological variability of the fruiting branches in *Argania spinosa*: Effects of seasonal variations, locality and genotype

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The argan tree, is a member of the tropical family Sapotaceae, is an endemic of south western Morocco appreciated for its edible, high nutritional oil, extracted from the kernels of the fruit. The total number of fruiting branches (F), with one (F1), two (F2), three (F3) and four or more fruits (F4) in ten units of four different types of branches were observed for three consecutive seasons in three localities in south west Morocco. The twigs of the season and those less than two seasons have not fruited even if they have flourished. In contrast, the twigs more than two seasons and the main branches bear fruits. Fruit production in argan tree is largely dependent on temperatures and rainfalls during the cycle of flowering and fruiting which covers about 16 months. Prolonged drought during the flowering season is manifested by a significant reduction of the fruiting branches and number of fruits on twigs during the fruit ripening season. Contribution in the phenotypic variance of the climatic season and tree x environment interaction were very significant (18.5 and 52.9%). Broad sense heritabilities were low and ranged between 0 and 14.4%. Differentiation between the three populations for the fruiting branches is not established. However, most trees from Argana and Ait Melloul were most fruit bearing. Argan is especially valued by its fruit and oil, this work shows the existence of significant potential to improve fruiting in this species, which is in the wild state, by the choice of plus genotypes and the optimization of fruit production techniques for the argan domestication as a fruit tree for oil production.

Key words: *Argania spinosa*, diversity, fruit, fruiting branches, repeatability, multivariate analysis.

INTRODUCTION

Fruit trees have the potential to contribute towards food security, nutritional health and income generation and mitigate environmental degradation in developing countries (Jamnadass et al., 2009; Cuni-Shanchez et al., 2011; Simbo et al., 2012). Plant growth and productivity is hampered by environmental conditions, such as water scarcity, recurrent aridity and others. Under these conditions, few species were capable to stand to adverse situation maintaining some productivity. Such is the case of *Argania spinosa* in arid and semi-arid areas of North Africa, able to provide a diversity of resources that are the basis of economy for the local population (Zunzunegui et al., 2010). This multi-purpose tree is often described as an endangered species since several physical and anthropogenic factors reduce the density and surface of the arganeraie ecosystem (Msanda et al.,

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2005). The argan tree is best known for its adaptation to drought and oil extracted from kernels of harvested fruit from trees in the wild state. However, the dried pulp, meal and leaves are sources of food for livestock (Sandret, 1957; Ehrig, 1974; M'Hirit, 1989, Prendergast and Walker, 1992; Maurin, 1992). Its exploitation is always in the economy picking mode. However, argan oil constitute up to 25% of fat consumed in the region. It is the subject of a commercial flow through Morocco and starts even if required at the international level for uses in dietetics and cosmetics. The multiple uses of the argan tree, especially the interest of oil combined with resistance to drought, make it a good candidate for domestication as a fruit tree for oil production and genetic improvement for arid areas (Bani-Aameur and Benlahbil, 2004; Ait Aabd et al., 2011).

Most of the reports available on the fruit were devoted to the chemical composition of argan oil, but very little research has focused on the fruit productivity in particular. The yield of fresh fruit varies according to tree, environment and climate season. It is 500 kg / ha / year per hectare on average (M'Hirit, 1989) and about 15 kg / tree (Rahali, 1989). The total production of ripe fruit in hot and dry season varies within wide limits according to trees at the Ait Melloul (Bani-Aameur, 2002a). Dried fruit yields are between 1.52 and 22.4 kg / tree / year. In addition, the frequency of fruit-bearing trees, fruit, pulp and kernel weights was highly variab Bani-Aameur le depending on season, trees and trees x environment interaction (Ferradous et al., 1996). These authors also reported that a minimum of 100 mm of rainfall recorded in autumn of fruit ripening promotes good fruiting. However large variability of flowering intensity was observed among climatic years, sites, tree genotypes and types of twigs. In any case, the peak of flowering occurs in spring (Bani-Aameur, 2002a). Small fruits on tree start to grow from October (Metro, 1952). But in February, fruits grow very quickly. In July, the fruit maturation was almost complete. The young fruits from flowering this season remain incompletely developed until the first rains next autumn. Thus, the flowering-fruiting cycle cover a period of nine to 16 months depending on trees (Bani Aameur et al., 1998; Benlahbil and Bani-aameur, 1999).

Some trees are able to have fruit once per season in March (early tree) or June (late tree), while other trees were able to flourish twice and then produce early and later fruits on the same individual (Ferradous et al., 1996; Bani Aameur et al., 1998). In early trees, the ripening of fruit from flowers fertilized in autumn of the last season occurs in May (Ferradous et al., 1996). In late trees, fruit maturation from flowers fertilized in spring of the last campaign occurs in August. While in intermediate trees, fruits are highly variable in size; their maturation is spread between spring and summer. All fruits from fertilized flowers do not persist until maturity, but a drop more or less important interested young fruit, ripe fruit and fruit whose maturation process is interrupted. The percentages of losses expressed in number of fruit varied from 3 to 39% depending on the trees (Bani Aameur et al., 1998). On the same tree, there are different branches and twigs with variable age and size. Twig of the season, twig less than two seasons, twig more than two seasons and the main branches growing on the carpenter branches (Zahidi et al., 1995). All these twigs and main branches bear flowers in very variable proportions (Ferradous et al., 1996; Bani-Aameur, 2000); we aimed to know what types can bear the fruits at maturity, and to establish the relationship between seasonal variations in temperatures and rainfall, the locality and the tree genotype and fruiting in three populations of argan in southwestern Morocco.

MATERIALS AND METHODS

Plant material and measurements

The experiment concerned trees was located at Ait Melloul at 35 m altitude in the Souss plain, Argana at 620 m altitude on southern slopes of High Atlas Mountains and Ait Baha (AB) at 50 km from the Atlantic ocean at 550 m altitude on the northern slopes of Anti Atlas mountains south west of Morocco. Thirty trees randomly selected and characterized for several morphological characters of fruit, kernel, flower, pollen, branching and foliation were observed in each site (Ferradous et al., 1996; Zahidi and Bani-Aameur, 1999a, b; Bani-Aameur and Benlahbil, 2004). Observations occur during three consecutive seasons, the first season was dry and warm; the second season was very wet with a relatively warm autumn, but winter and spring were cold. The third season is characterized as wet and hot, with gaps relatively high between the minimum and maximum temperatures (Figure 1).

Among the twigs and main branches facing South because of its large flowering (Bani-Aameur, 2002a), we observed at the end of April for three consecutive seasons the following characters (Figure 2): Among the 10 twigs of the season labeled (green twigs) we counted: Total number of the fruiting twigs (F); number of twigs with one fruit (F1); number of twigs with two fruits (F2); number of twigs with three fruits (F3); number of twigs with four or more fruits (F4). The same operation is performed for the ten twigs less than two seasons labeled (red color), ten twigs more than two seasons (lignified) and 10 principal branches (lignified with different ages and dimensions).

Variability characterization

The variance components and the relative percentage of the variance related to different factors in the total variance were estimated using the model in Table 1:

$$\sigma^2 T = \sigma^2 A + \sigma^2 l + \sigma^2 A \times l + \sigma^2 a/l + \sigma^2 A \times a/l + \sigma^2 e$$

Where, σ^2 T, Total variance (phenotypic variance); σ^2 A, variance related to seasonal variations (season factor); σ^2 l, variance due to locality; σ^2 A x l, variance due to season x locality interaction; σ^2 a/l, variance due to tree / locality (genotype); σ^2 A x a/l, variance related to genotype x environment interaction (season x tree / locality); and σ^2e: variance due to error. The percentage of the variance of each factor in phenotypic variance per each site was calculated using the model in Table 1.

$$\sigma^2 Ts = \sigma^2 A + \sigma^2 a + \sigma^2 A \times a + \sigma^2 e$$

Where, σ^2Ts, Total variance by site; σ^2A, variance related to season; σ^2a, variance due to tree; σ^2A x a, variance due to season x tree interaction; σ^2e: variance by site due to error.

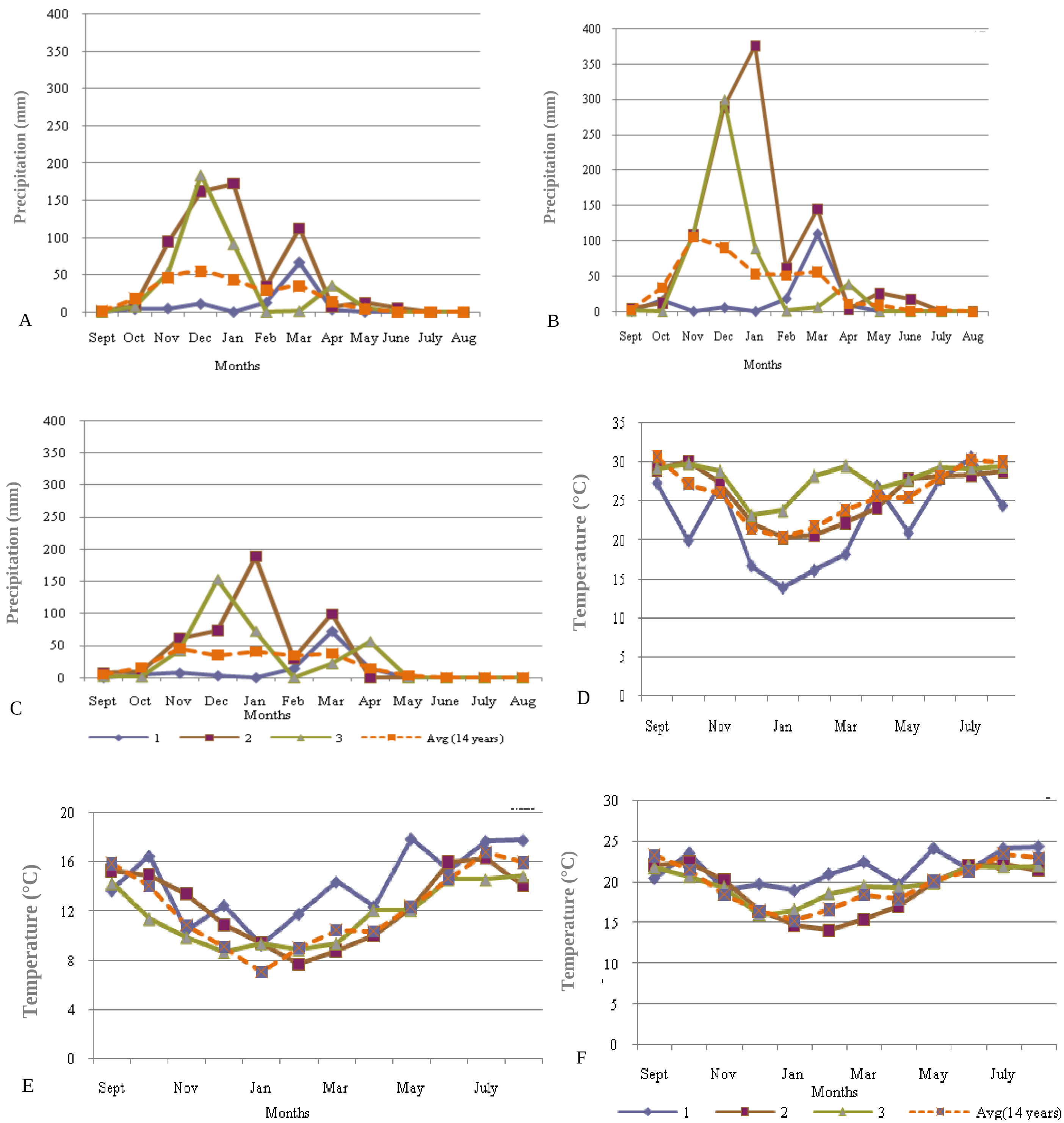

Figure 1. Climatic data from meteorological stations: mean monthly precipitation (mm), maximum, minimum and mean temperatures recorded at Ait Melloul (AM), Argana (AR) and Ait Baha. A, AM; B, AR; C, AB; D, max; E, min; F, avg.

Repeatability (broad sense heritability estimated by the ratio of variance tree / locality to the total phenotypic variance) was calculated according to the formula below given that trees are not repeated between sites and in each site (Pfahler et al., 1996; Bani-Aameur et al., 2001):

$$r^2 = 100 \times (\sigma^2 a/l \; / \; \sigma^2 a/l + \sigma^2 A \times a/l + \sigma^2 e)$$

Where the sum $\sigma^2 a/l + \sigma^2 A \times a/l + \sigma^2 e$) represents the total phenotypic variance in the three site and ($\sigma^2 a/l$) constitute the

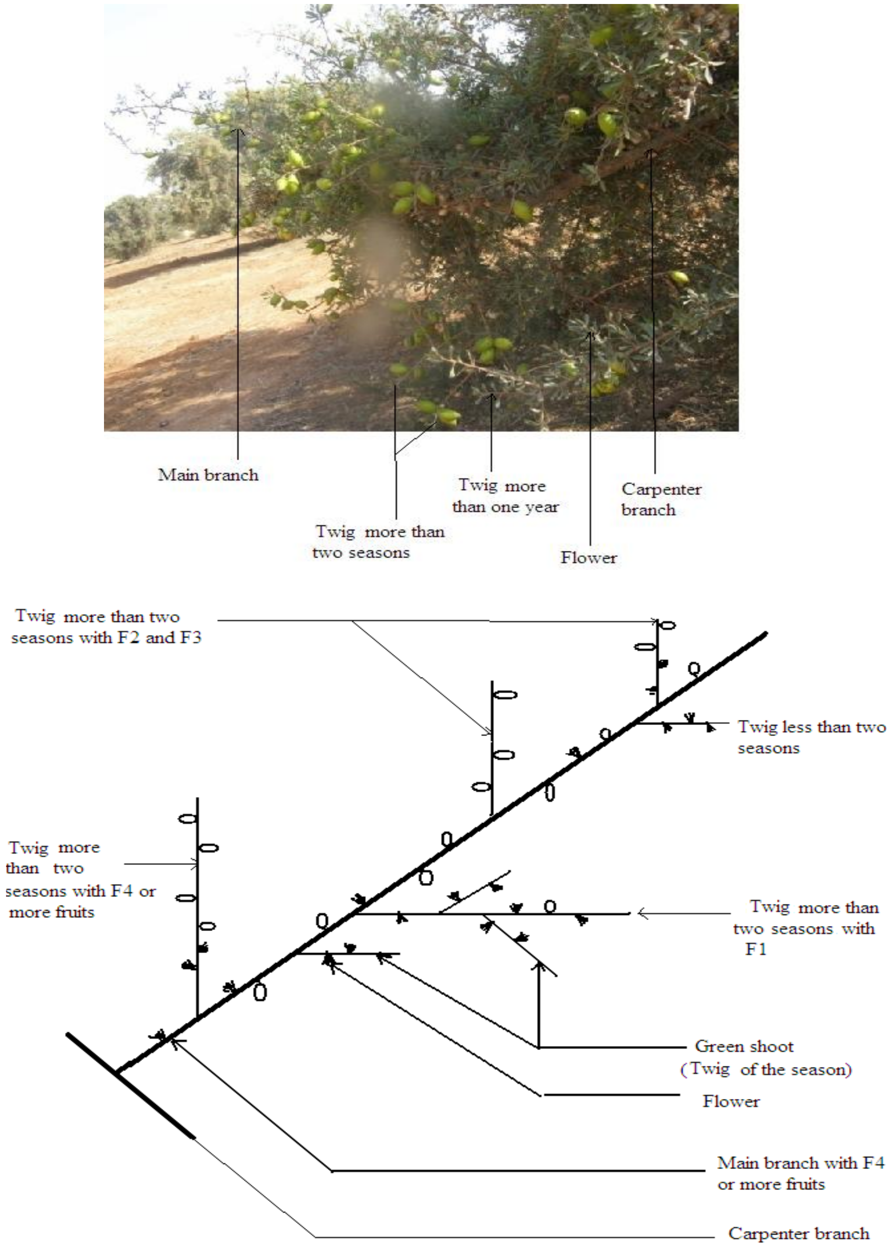

Figure 2. Morphological characters of the fruiting branches observed in Ait Melloul, Ait Baha and Argana during three consecutive seasons.

genetic variance. The repeatability per site was estimated using the following model:

$r^2 = 100 \times (\sigma^2 a \ / \ \sigma^2 a + \sigma^2 A \times a + \sigma^2 e)$

Where the sum ($\sigma^2 a + \sigma^2 A \times a + \sigma^2 e$) represents the total phenotypic variance per locality and ($\sigma^2 a$) variance related to tree.

Data analysis

An analysis of variance with four factors in hierarchical model was adopted (Table 1). Genotype (tree / locality) is hierarchical to locality factor because trees are not repeated between sites. Climatic season, locality and type of branch were crossed. The least significant difference test (LSD α = 5 %) of equality of means was used to compare differences between means (Steel and Torrie, 1960; Dagneli, 1984; Sokal and Rohlf, 1995). Factorial discriminate analysis (AFD) was performed on annual averages of each tree in order to examine the simultaneous contribution of all parameters studied in discriminating trees and sites (Frontier, 1981; Bernstein et al., 1988).

Dendogram was built using clustering method UPGMA "pair-group method unweighetd arithmetic average". Statistical treatments were performed using Statitcf, Statistix software and Ntsys version 1.40 (Rohlf, 1988).

Table 1. Expectations of mean squares and estimated variance components for morphological characters in the three localities.

Source of variation	DF	Mean square	Expectations of mean squares
Global			
Season	2	CM A	$\sigma^2e + 2\sigma^2Aal + 60\sigma^2Al + 180\sigma^2A$
Locality	2	CM l	$\sigma^2e + 2\sigma^2Aal + 60\sigma^2Al + 6\sigma^2al + 180\sigma^2l$
Tree / locality	87	CM al	$\sigma^2e + 2\sigma^2Aal + 6\sigma^2al$
Season x locality	4	CM Al	$\sigma^2e + 2\sigma^2Aal + 60\sigma^2Al$
Season x tree / locality	174	CM Aal	$\sigma^2e + 2\sigma^2Aal$
Error	270	CM e	σ^2e
By locality			
Season	2	CM A	$\sigma^2e + 2\sigma^2Aa + 60\sigma^2A$
Tree	29	CM a	$\sigma^2e + 2\sigma^2Aa + 6\sigma^2a$
Season x tree	58	CM Aa	$\sigma^2e + 2\sigma^2Aa$
Error	90	CM e	σ^2e

Table 2. Analysis of variance of number of main branches and twigs more than two seasons fruit bearing (F), with one (F1), two (F2), three (F3) and four or more fruits (F4) observed in the three localities.

Source of variation	DF	Mean square				
		F	F1	F2	F3	F4
Season	2	2806.8*	579.3^{ns}	282.9**	81.46*	26.2^{ns}
Locality	2	749.01^{ns}	248^{ns}	27.8^{ns}	32.5**	28.6**
Type of branch	1	90.7^{ns}	1.13^{ns}	12.03^{ns}	12.3^{ns}	12.9^{ns}
Tree / locality	87	14.25^{ns}	5.5^{ns}	2.03^{ns}	1.81**	1.5**
Season x locality	4	234.6**	125.03**	8.88**	8.5**	8.45**
Season x type of branch	2	52.64*	6.6^{ns}	2.88**	6.89**	7.85**
Locality x type of branch	2	11.27^{ns}	2.07^{ns}	0.76^{ns}	1.6*	2.26*
Season x locality x type of branch	4	6.34**	1.82^{ns}	0.86^{ns}	0.9^{ns}	0.82^{ns}
Season x tree / locality	174	12.14**	5.96**	1.76**	1.31**	1.12**
Season / locality x type of branch	87	1.83^{ns}	1.05^{ns}	0.61^{ns}	0.36^{ns}	0.5*
Season x tree / locality x type of branch	174	1.34^{ns}	1.13^{ns}	0.57**	0.38**	0.39**
Error	540	1.45	1.26	0.4	0.25	0.21

^{ns}Not significant; *: significant at 5%; **, significant at 1%.

RESULTS

Variability characterization

Type of branch

The principal branches and twigs more than two seasons have borne fruits for three seasons, but twigs of the season and those less than two seasons have not borne fruits at maturity even if they have flowered. The type of branch was not significant for all traits (F, F1, F2, F3 and F4) (Table 2). Type of branch x climatic season interaction is significant for total number of fruiting the twigs (F), number of twigs to two (F2), three (F3) and four or more fruits (F4), but not significant for number of twigs with one fruit (F1). Locality x type of branch interaction was significant for F3 and F4. Locality x climatic season x type of branch interaction was significant only for F. Type of branch x tree / locality interaction (genotype x type of branch) was significant for F4, while climatic season x type of branch x tree / locality interaction was highly significant for F2, F3 and F4.

During the second season (2nd) characterized as low fruiting and even during the season at intermediate fruiting (1st), no difference was found between the main branch and twig over than two seasons for F1, F2, F3 or F4. But, in season of high fruiting, twigs more than two seasons have borne more fruits (72%) than the main branch (57.3%). They bear more than one fruit in 58.9% of cases against 48.2% for main branch (Table 3).

In all three localities, no difference was observed for F, F1 and F2 between the main branches and twigs more

Table 3. Average number of branches (main branch and twigs more than two seasons) with fruits (F), one (F1), two (F2), three (F3) and four or more fruits (F4) per season observed in three localities.

Type of branch	Season	Main branch	Twig more than two seasons
Twig or main branch with fruits (F)	1	4.13	4.17
	2	0.78	1.02
	3	5.73 b	7.19 a
	Average	3.55	4.13
Twig or main branch with one fruit (F 1)	1	2.82	2.47
	2	0.54	0.73
	3	3.01	2.97
	Average	2.12	2.06
Twig or main branch with two fruits (F 2)	1	0.66	0.8
	2	0.16	0.24
	3	1.72 b	2.14 a
	Average	0.85	1.06
Twig or main branch with three fruits (F 3)	1	0.42	0.55
	2	0.06	0.05
	3	0.74 b	1.28 a
	Average	0.41	0.63
Twig or main branch with four or more fruits (F 4)	1	0.2	0.32
	2	0.01	0.0
	3	0.3 b	0.82 a
	Average	0.17	0.38

Means followed by letters are significantly different at 5%.

Table 4. Average number of branches (main branch and twigs more than two seasons) with fruits (F), one (F1), two (F2), three (F3) and four or more fruits (F4) observed in Ait Melloul (AM), Argana (AR) and Ait Baha (AB).

Type of branch	Main branch				Twig more than two seasons			
	AM	AR	AB	Average	AM	AR	AB	Average
With fruit (F)	4.18	4.37	2.09	3.55	4.99	5.13	2.26	4.13
With one fruit (F 1)	2.87	2.25	1.25	2.12	2.93	2.02	1.23	2.06
With two fruits (F 2)	0.92	1.04	0.59	0.85	1.17	1.31	0.7	1.06
With three fruits (F 3)	0.33^b	0.7^b	0.22^b	0.41	0.58^a	1.01^a	0.28^a	0.62
With four or more fruits (F 4)	0.67^a	0.4^b	0.02^b	0.16	0.3^b	0.77^a	0.07^a	0.38

Means followed by different letters are significantly at 5%.

than two seasons (Table 4). In Argana and Ait Baha, the twigs more than two seasons have more fruits, four or more fruits in greater proportions than the main branch. In Ait Melloul, twigs more than two seasons had formed three fruits in greater proportions, but the main branches had formed more than four fruits. In the three sites, main branches and twigs more than two seasons are capable of producing at least one or two fruits, but the young twigs (twig more than two seasons) have a higher production potential than older branches (main branches). All trees have not borne the same number of twigs with three, four or more fruits. In trees (1, 4, 5, 14, 23 and 29) from Ait Melloul, (2, 5, 6, 13, 17, 20, 19 and 27) from Argana and (2, 11 and 20) from Ait Baha, the twigs more than two seasons have more fruits than the main branches. While among the trees (20, 21 and 25) of Ait Melloul (11, 18 and 28) of Argana, and (21, 22, 30) of Ait Baha, the main branches were more fruiting than the

Table 5. Average number of branches (main branches and twigs more than two seasons) with fruit (F), one (F1), two (F2), three (F3) and four or more fruits (F4) per season and locality.

Type of branches	Season \ locality	Ait Melloul	Argana	Ait Baha	Average
Number of branches with fruits (F)	1	5.94^{b}	5.81^{b}	0.7^{b}	4.15^{b}
	2	1.38c	1.01c	0.32c	0.9c
	3	6.44^{a}	7.43^{a}	5.51^{a}	6.46^{a}
	Average	4.59	4.75	2.18	3.84
Number of branches with one fruit (F1)	1	4.5^{a}	2.87^{a}	0.56^{b}	2.64
	2	1.07c	0.7^{b}	0.16c	0.64
	3	3.13^{b}	2.84^{a}	3.0^{a}	2.99
	Average	2.89	2.13	1.24	1.99
Number of branches with two fruits (F2)	1	0.93^{b}	1.18^{b}	0.08^{b}	0.73^{b}
	2	0.27c	0.23c	0.1^{b}	0.2c
	3	1.93^{a}	2.12^{a}	1.74^{a}	1.93^{a}
	Average	1.04	1.18	0.64	0.95
Number of branches with three fruits (F3)	1	0.37^{b}	1.04^{b}	0.05^{b}	0.5^{b}
	2	0.05c	0.06c	0.06^{b}	0.06c
	3	0.95^{a}	1.43^{a}	0.64^{a}	1.01^{a}
	Average	0.46^{b}	0.84^{a}	0.25c	0.52
Number of branches with four or more fruits (F4)	1	0.07^{b}	0.7^{b}	0^{b}	0.26
	2	0^{b}	0c	0.03^{b}	0.01
	3	0.48^{a}	1.06^{a}	0.11^{a}	0.55
	Average	0.18^{b}	0.59^{a}	0.04c	0.27

Means followed by different letters are significantly at 5%.

twigs more than two seasons.

Climatic season

The climatic season is significant for F, F2 or F3 (Table 2). It is not significant for F1 and F4. The fructification is higher during the third season compared to the first and second seasons (Table 5). Indeed, during the humid season (3rd) following a very humid campaign, 65% of main branches and the twigs more than two seasons have fructified. Whereas during very dry season (1st) following a dry campaign, 41.5% of total of the twigs or main branches observed have borne fruits, while during the campaign very humid (2nd) following a very dry season, about 9% of main branches and the twigs more than two seasons have fructified. Among these fruiting the twigs, 45.5% in the 3rd season, 29.6% in the 1st and 28.8% in 2nd season had borne two or three fruits.

Locality

Locality is highly significant for F3 and F4, but not significant for F, F1 and F2 (Table 2). Locality x climatic season interaction is highly significant for all traits. In Argana site, number of twigs or main branches to three and four or more fruits is higher than in Ait Melloul, and Ait Baha (Table 5). Reducing the number of fruits on the branches is probably a reaction to variations of temperatures and rainfalls. This reduction was more pronounced in Ait Baha, more arid site than in Ait Melloul to mild temperatures and Argana the most humid site especially during the 1st and 2nd season (Table 5). These effects are manifested by a remarkable reduction in the number of fruiting branches, since 7% of the total branches during the dry season and only 3.2% in very humid season following a dry campaign have fruited in Ait Baha. In the three stations, in season at low and intermediate fruiting, most (over 50%) of branches bear fruits. In contrast, in season at high fruiting, 62.1% in Argana, 52.2% at Ait Melloul and 45.1% Ait Baha having more than one fruit.

Genotype

Tree / locality (genotype) is highly significant for F3 and F4 (Table 2). Indeed some trees as (6 and 10) of Ait Melloul, (6, 7, 11, 17, 26, 27 and 28) of Argana (4 and 21) from Ait Baha were able to produce more fruiting branches (main branches or twigs more than two seasons) with three and with four or more fruits and therefore more fruits. So, these trees are of high potential

Table 6. Frequencies of trees that produced fruits at Ait Melloul, Argana and Ait Baha.

Type of branch	Season \ locality	Ait Melloul		Argana		Ait Baha		Average	
		Number of trees	Frequency (%)	Number of trees	Frequency	Number of trees	Frequency (%)	Number of trees	Frequency (%)
Branches with one fruit (F1)	1	28	93.3	27	90	9	30	21.3	71
	2	13	43.3	7	23.3	2	6.7	7.3	24.4
	3	30	100	30	100	30	100	30	100
Branches with two fruits (F2)	1	15	50	25	83.3	4	13.3	14.7	48.9
	2	13	43.3	6	20	2	6.7	7	23.3
	3	30	100	30	100	30	100	30	100
Branches with three fruits (F3)	1	6	20	21	70	2	6.7	9.7	32.2
	2	3	10	5	16.7	2	6.7	3.3	11.1
	3	28	93.3	30	100	27	90	28.3	94
Branches with four or more fruits (F4)	1	1	3.3	13	43.3	0	0	4.7	16
	2	0	0	0	0	2	6.7	0.7	2.2
	3	21	70	25	83.3	8	26.7	18	60

for fruit production and then can serve as germplasm in a breeding program and for domestication as a fruit tree for the production of argan oil. Season x tree / locality interaction is highly significant for all traits (Table 2). Trees in the three sites have reacted differently with respect to seasonal variations of temperatures and rainfalls (Table 6). This differential response was reflected by the frequency of trees whose fruiting branches have presented one fruit, two, three and four or more fruits. Thus, during the very humid season (2), following a very dry season, 6.7% of total trees at Ait Baha, 23.3% in Argana and 43.3% in Ait Melloul were fruitful. While during the humid season (3), which followed a very humid campaign all trees have borne fruits. During the first season, which followed a dry campaign, about 93.3% in Ait Melloul and Argana and 30% in Ait Baha have fruited.

Variance components

The relative percentage of variance due to climatic season in the total variance is high more than 50% for F and F2, but relatively low to moderate (8% to 28%) for the others characters (Figure 3). Climatic season effect is more pronounced at Ait Baha than in Argana and Ait Melloul for all characters except number of branches (twigs more than two seasons and main branches) to four or more fruits. The percentages of total variance per site varied between 44.1 and 83.4% in Ait Baha, 26.1 and 70.9% in Argana, and between 35.4 and 61.5% in Ait Melloul. The relative contribution of variance related to locality and locality x season interaction in the phenotypic variance is relatively low and ranged from 3.6 and 13.2% except the number of branches with one fruit (22.7%) The contribution of variance due to genotype x environment interaction (season x tree / locality) in phenotypic variance is greater for all characters. It varied from 18.5% for F and 42.8% for F4 (Figure 3). Percentages remarkable of genotype x environment interaction are mainly related to the importance of season x tree interaction in Ait Melloul and Argana compared to Ait Baha. Thus, at Ait Melloul and Argana where seasonal variations are less important, season x tree interaction explains 30.1 to 59.9% in Ait Melloul and about 0 to 44.4% in Argana. By cons, at Ait Baha, the driest site, this contribution varied from 8.6 to 57.1%. The relative contribution of variance associated to genotype (tree/locality) in the phenotypic variance is low and ranged from 0% for F1 and 6.2% for F4 (Figure 3). The same observation is noted in each locality, the percentage of total variance attributed to tree factor is also low (0% for F, F2, F3 and 7.7% for F4). Highest repeatabilities (8.9 and 9.8%) were observed for F3 and F4, while for the other characters, the repeatabilities were low (0 and 4.8%) (Table 7). Low repeatability (overall and by station) recorded for the fruiting branches reflect the crucial role of seasonal variation in the fruits productivity in argan tree.

Variability distribution

The total number of the fruiting branhes (F) is correlated in different degrees with F1, F2 and F3 during the dry season (1^{st}), and during the very humid season (2^{nd}) (Table 8). While during the humid season (3^{rd}), F is highly correlated with F2, F3 and F4. The correlation coefficients of F1 were low in very dry season but higher with F2, F3 in very humid season and F3, F4 in humid

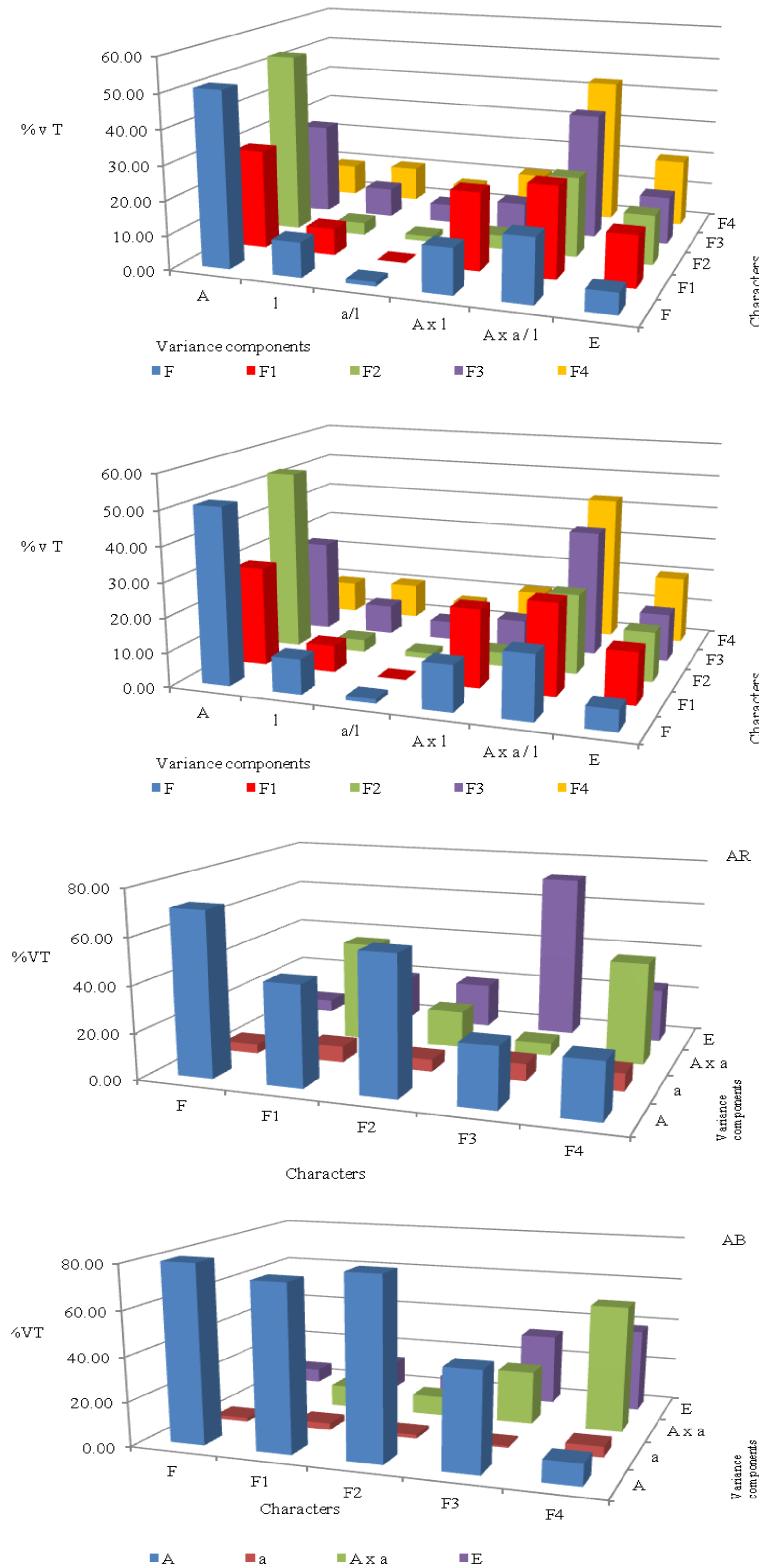

Figure 3. Percentage in phenotypic variance of variance components for main branches and twigs more than two seasons with fruit (F), with one (F1), two (F2), three (F3) and four or more fruits (F 4) observed in Ait Melloul (AM), Argana (AR) and Ait Baha (AB). (A, Season, l, locality, a / l, tree / locality, a, tree, A x l, season x locality; A x a / l, season x tree / locality; e, error).

Table 7. Repeatabilities in percentage for the fruiting branches observed in the three localities.

Character	F	F1	F2	F3	F4
Global	4.8	0.0	4.04	9.8	8.9
Ait Melloul	0.0	1.03	0.0	0.00	5.4
Argana	14.4	0.0	12.7	10.1	10.2
Ait Baha	10.2	11.8	8.9	0.0	0.0

Table 8. Matrix of correlations for the fruiting branches observed in the three localities during the three consecutive seasons.

Characters	Fs1	Fs2	Fs3	F1s1	F1s2	F1s3	F2s1	F2s2	F2s3	F3s1	F3s2	F3s3	F4s1	F4s2	F4s3
Fs1	1.00														
Fs2	0.15	1.00													
Fs3	0.43	0.21	1.00												
F1s1	0.75	0.12	0.23	1.00											
F1s2	0.16	0.97	0.18	0.14	1.00										
F1s3	-0.01	-0.02	-0.1	0.14	0.01	1.00									
F2s1	0.67	0.13	0.25	0.23	0.16	0.02	1.00								
F2s2	0.11	0.93	0.21	0.1	0.84	-0.03	0.08	1.00							
F2s3	0.32	0.17	0.73	0.22	0.166	-0.11	0.19	0.18	1.00						
F3s1	0.58	0.1	0.4	-0.03	0.09	-0.19	0.56	0.09	0.2	1.00					
F3s2	-0.03	0.69	0.14	0.01	0.53	-0.06	-0.06	0.77	0.07	0.01	1.00				
F3s3	0.32	0.15	0.82	0.15	0.11	-0.49	0.13	0.15	0.49	0.37	0.13	1.00			
F4s1	0.43	-0.01	0.35	-0.06	-0.03	-0.23	0.18	0.01	0.25	0.67	-0.03	0.24	1.00		
F4s2	-0.13	0.34	-0.1	-0.1	0.21	0.06	-0.07	0.45	-0.03	-0.08	0.7	-0.11	-0.05	1.00	
F4s3	0.33	0.21	0.78	0.08	0.19	-0.53	0.2	0.2	0.4	0.44	0.15	0.78	0.37	-0.1	1.00

season. The values of F, F1, F2, F3 and F4 obtained in the dry season were not correlated with the values of humid seasons.

Discriminate factorial analysis shows that 100% of the total variance could be explained using only the two canonical components. First CP1, explaining about 69.5% of variation, was linked to F, F2 and F3 in the three seasons, to F1 in the 1st and 2nd season, and F4 in the 2nd and 3rd season. Thus individuals to high fruiting such as (1, 2 and 3) of Ait Melloul, (1, 3 and 23) of Argana and (27) of Ait Baha were projected on the negative side of the first axis. But, individuals with low fruiting such as (8 and 15) of Ait Melloul (4 and 24) of Argana and great number of trees from Ait Baha were projected on the negative side of this axis (Figure 4). Second CP2 that was responsible for 30.5% of variation is linked to F1 in 3rd season and F4 in 1st season, to F, F4 and F2 in 3rd season and in varying degrees to F3 in the three seasons (Table 9).

The ordering of trees revealed that genotypes are not grouped according to their origins since respectively 58.9% (53/90 trees) from Ait Melloul, 48.8% (44/90 trees) from Argana are among trees most fruiting and which produce three and four fruits. But more than 60% of trees from Ait Baha are among genotypes low fruiting. We can therefore conclude that there is no differentiation of the three populations for the fruiting branches. Ait Melloul and Argana sites are relatively far from Ait Baha, while Ait Melloul and Argana are nearer (Table 10).

The dendrogram generated based on all morphological traits, showed a similar pattern. Two groups are distinguished in a Euclidean distance 3.2 (Figure 5). The first group is divided in a Euclidean distance of 2.74 in a first class containing M15, R24 and B22 characterized by low fruiting, and a second class containing 13.9% from Ait Melloul, 16.7% from Argana and 69.4% from Ait Baha. The second group is divided in a Euclidean distance of about 2.63 into two subgroups. The first subgroup includes 39.4% from Ait Melloul, 51.5% from Argana, and 9.1% from Ait Baha. The second subgroup contains 61.1% from Ait Melloul, 33.3% from Argana and 9.1% from Ait Baha. Sites classification shows two groups at a Euclidean distance about 2.56 (Figure 6). A first group consists Ait Baha and a second group containing Ait Meloul and Argana. This classification is not the result of geographical isolation. Argana characterized by cold winter, and Ait Melloul with mild temperatures are generally not differentiated from Ait Baha known for its drought summer.

DISCUSSION

The main branch and the twigs more than two seasons

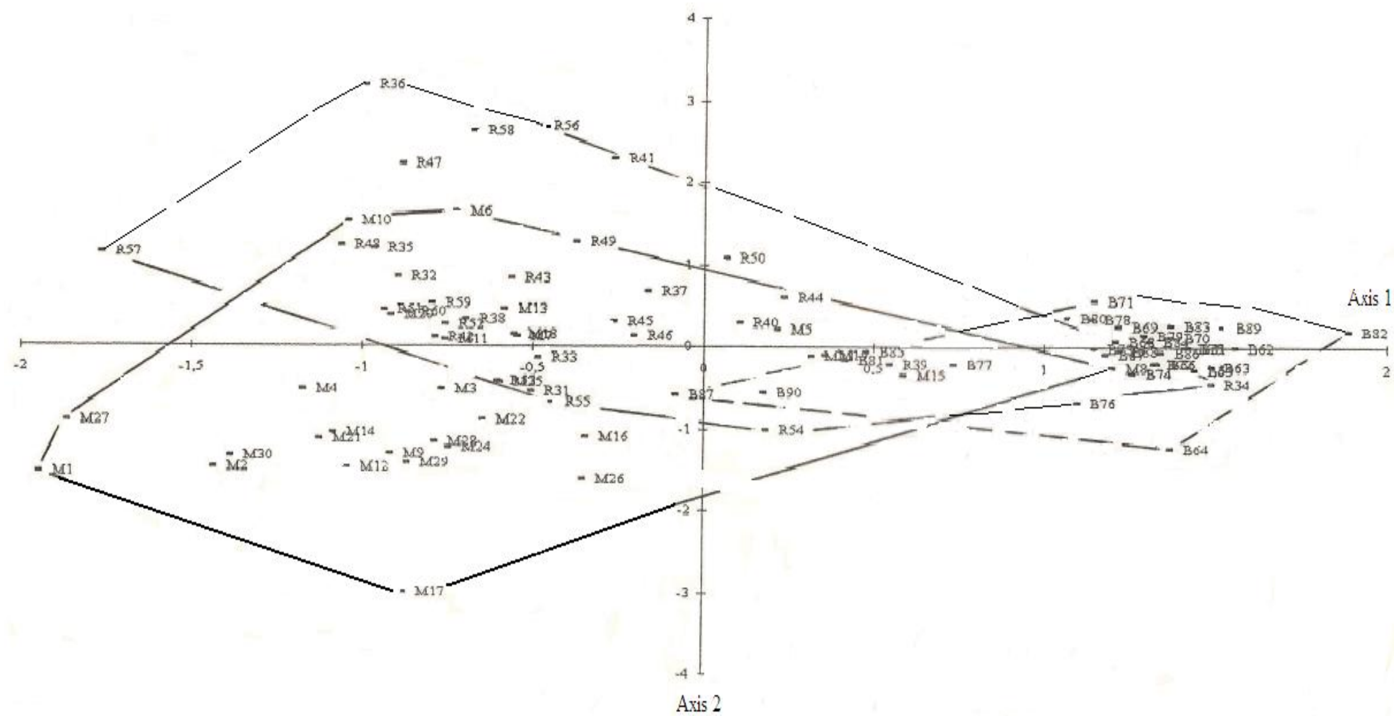

Figure 4. Projection of individuals from the three populations on the plane defined by the first two canonical components.

Table 9. Correlations between canonical components and characters of the fruiting branches observed in the three localities.

Variable	CP1	CP2
Fs1	-0.99	0.1
Fs2	-0.97	-0.24
Fs3	-0.8	0.61
F1s1	-0.95	-0.31
F1s2	-0.95	-0.31
F1s3	-0.04	-0.99
F2s1	-0.95	0.32
F2s2	-0.99	-0.15
F2s3	-0.81	0.58
F3s1	-0.67	0.74
F3s2	0.6	0.81
F3s3	-0.73	0.69
F4s1	-0.48	0.88
F4s2	0.99	-0.11
F4s3	-0.72	0.69
Eigenvalues	0.68	0.3
Explained Percentages (%)	69.5	30.5
Cumulative percentages (%)	69.5	100

CP1, First canonical component; CP2, second canonical component.

have borne the fruits during the three campaigns, but the twigs of the season and those less two seasons have not borne the fruits at maturity even if they have flowered. The type of branch (main branches or twigs more than two seasons) does not affect the fruiting of argan tree. However, the fruiting is strongly influenced by the season, locality and tree. The twigs more than two seasons are more fruiting than the main branches in

Table 10. Mahalanobis distance between Ait Melloul, Argana and Ait Baha for characters of the fruiting branches.

Locality	Ait Melloul	Argana	Ait Baha
Ait Melloul	0		
Argana	1.35	0	
Ait Baha	1.92	1.81	0

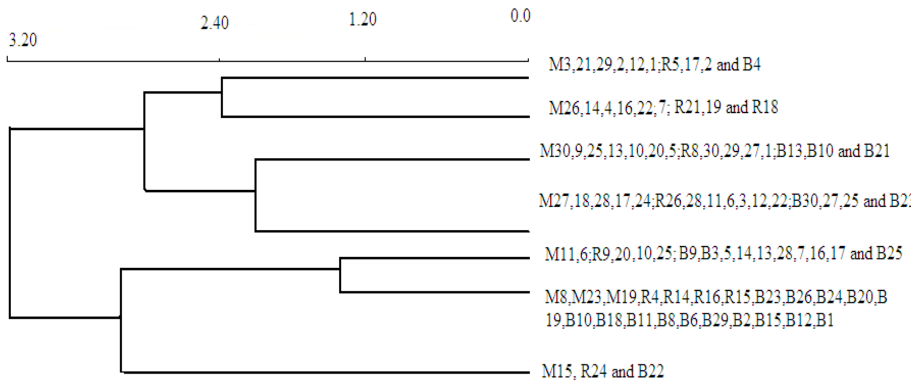

Figure 5. Dendrogram obtained when clustering individuals of Ait Melloul (M), Argana (R) and Ait Baha (B) on the basis of characters of the fruiting branches characters.

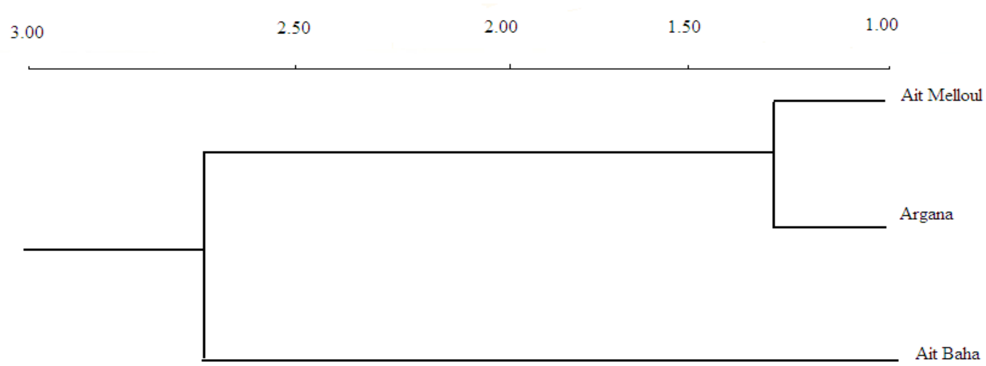

Figure 6. Classification of localities Ait Melloul (AM), Argana (AR), and Ait Baha (AB) for characters of the fruiting branches in argan tree.

favorable seasons. It seems that this difference has a trophic origin in relation to the age of the branches. Thus, for the regulation of the fruiting in argan tree, pruning-lightening operations by removing some old branches that grow on the carpenter branches reduces nutrient competition and ensure regularity of fruit production in argan as is practiced in other fruit species (Andales et al., 2006; Tworkoski and Glenn, 2010). For the establishment of orchards, this operation must be coupled with an appropriate irrigation in case of drought, at least during the flowering period since 100 mm of rainfall recorded in autumn of fruit ripening promotes good fruiting as reported by Bani-Aameur (2002a) and Bani-Aameur (2002a). Those operations must take into account yield components (number of fruiting branches, number of flowers, number of fruits per flower).

In a given season, in the three localities, all trees do not bear fruits. The effect of drought occurs partly by a reduction in number of branches with fruits and secondly by reducing the number of fruit on the twigs. The flowering-fruiting cycle cover a period of 9 to 16 months depending on trees (Bani Aameur et al., 1998; Benlahbil and Bani-aameur, 1999). Thus, in case of drought during the flowering period, most fruiting branches in the next season produce mainly one or two fruits and secondarly three fruits. But, if the flowering season is humid, fruiting in the following season will be more important and number of branches bearing fruits will be also higher. Significant decrease in the number of the fruiting branches and the number of fruits on twigs during the very humid season (2nd) is related to minimum flowering observed during the previous season characterized as dry and warm. Indeed, during the dry seasons, the flowering was late (March), it concerned only 50 to 70% of trees in the three sites and the number of glomerules ranged from 0.18 to 24 units. By cons, during the humid seasons, all trees have flowered, and the number of glomerules ranged from between 10 and 74 units (Benlahbil and Bani-aameur, 1999).

In addition, the percentage of losses expressed in number of fruits due to physiological drop (young fruits), which interrupted the process of maturation and ripe fruits ranged from 3 to 39% depending on the tree in hot and dry season (Bani Aameur et al., 1998). It appears that the adjustment of fruiting was a response to unfavorable conditions by a reduction in number of fruits on the branches. If the effects of the climatic season were manifested in the three localities by a reduction of fruiting during the second campaign, it appears that Ait Baha site was the most affected than Ait Melloul and Argana during the dry season (1st) and during the very humid season (2nd). Thus, at Ait Baha, this reaction is manifested by a very limited number of trees producing fruits (9 trees in first season, and 2 trees in second season) and a reduction in number of fruit-bearing branches. These observations confirm the findings reported by Ferradous et al. (1996) for the frequency of trees bearing fruits, weight of fruit, kernel and pulp where the effects of climatic year was perceived at Ait Baha. This station will be considered as a medium for selection of resistant genotypes to drought.

Trees in the three populations have reacted differently to seasonal variations of temperatures and rainfalls. Some individuals from Ait Baha (4 and 21), (6 and 10) of Ait Melloul and (6, 7, 11, 17) of Argana have borne the fruits in dry seasons or in humid seasons. But other trees have not borne fruits in the same conditions. Those behaviors have been observed previously since frequencies of trees that borne fruits differ mainly at Ait Melloul and Argana (Ferradous et al., 1996) confirm the impotance of genotype, in addition to seasonal variation in determining the fruiting in Argan tree. In argan, there are two categories of genotypes. Some genotypes are able to produce fruits even under unfavorable conditions. Other genotypes may only bear the fruits if temperatures and rainfalls are in favor of the flowering and ripening fruits. Trees from Ait Baha are the most affected by these changes of environmental conditions.

The relative percentage of variance related to seasonal variations in the phenotypic variance is higher than that observed for fruits characters (0.71% and 11.2%). But, this contribution related to locality and season x locality interaction was relatively low as reported by Bani-Aameur et al. (2001) (0.7 to 4.2%) except the fruit color (64.8%) and for characters of simple leaves (0.5 and 17.9%) (Zahidi, 2004). These results confirm the idea that argan tree shows a high adaptive plasticity with respect to his living environment, as has been noticed in other plant species (Sultan, 2000; Mückschel and Otte, 2003; Ait Aabd et al., 2011).

Genotype x environment interaction (season x tree / locality) contribution in the phenotypic variance is remarkable for the studied characters of the fruiting branches. This result is also observed for characters of fruit (10.4 and 14.7%) (Bani-Aameur et al., 2001). But, genotype (tree / site) contribution in the total variability is very low. These values are low compared to those obtained in sour cherry germplasm collected from the most important growing regions in Serbia. The highest degree of variability was observed number and composition of the fruiting branches, fruit set and yield (Rakonjac et al., 2010); and for characters of fruit (7.5 and 43.9%) (Bani-Aameur et al., 2001). Repeatabilities observed for the fruiting branches are much lower than those recorded for simple leaves characters except leaf dry weight (21.4 and 56.9%) (Zahidi, 2004), for fruit characters (8.02% for number of almonds and 93.28% for oil content (Bani-Aameur et al., 2001; Ait Aabd et al., 2011).

In the fruiting branches, intra-population variability (difference between trees in the same locality) is more important than inter-population variability (difference between localities). In addition, Euclidienne distance calculated based on characters of the fruiting branches is similar to that obtained for fruit and kernel (3.2) (Ferradous, 1995), but low in walnut (*Julans regia* L.) on the basis of leaf (4.6) and fruit (6.4) characters (Malvolti et al., 1994). So, differentiation of the three populations is not established since classification of individuals does not coincide with the groups that belong to the sites. This classification is not the result of geographic isolation; Ait Melloul and Argana with different climatic characteristics are not differentiated from Ait Baha. This result is confirmed by low contribution of variance related to locality (σ^2 inter-populations + σ^2geographical) in the phenotypic variance for the fruiting branches. But a large heterogeneity between trees is observed because approximately 93.3% of trees from Ait Baha, 13.3% of Ait Melloul and 6.7% of Argana are ranged in group of small producers. While about 93.3% of trees from Argana, 86.7% of Ait Melloul and 6.7% of Ait Baha (4 and 21) were among the fruit producers.

Dinis et al. (2011) suggested that annual climate conditions influence significantly the fruits and leaf characters. In addition, the morphological and phonological differences among ecotypes were not related to the small genetic differences, but were simply phenotypic adaptations to different climatic conditions. Both trees from Ait Baha, and some genotypes from Ait Melloul and Argana can produce fruits even in an arid environment will be used as germoplasm for domestication of argan as a fruit tree for oil production.

Conclusion

The main branch and the twigs more than two seasons have borne the fruits during the three campaigns, but the twigs of the season and those less two seasons have not borne the fruits at maturity even if they have flowered. The fruiting in argan tree is dependent on temperatures and rainfalls especially during the flowering season. For the establishment of orchards, the choice of efficient genotypes, pruning-lightening operations coupled with an appropriate irrigation in case of drought, at least during the flowering period should be taken into account. Differences observed for characters of the fruiting branches between trees and between localities indicate that an important genetic variation exists between individuals within each site. Ait Baha site is less far to Ait Melloul and Argana, but having some good genotypes with a high production potential even in unfavorable conditions. This variability can be exploited for the selection of desirable genotypes for breeding programme. Moreover, this result has practical implications for genetic management of resource for futur domestication programs of argan as oil-producing tree which is still in the wild state.

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REFERENCES

Ait Aabd N, El Ayadi F, Msanda F, El Mousadik A (2011). Evaluation of agromorphological variability of argan tree under different environmental conditions in Morocco: implication for selection. Int. J. Biodiver. Conserv. 3(3):73-82.

Andales A, Wang J, Sammis TW, Mexal JG, Simmons LJ, Miller DR, Gutschick VP (2006). A model of pecan tree growth for the management of pruning and irrigation. Agric. Water Manage. 84(1-2):77-88.

Bani-Aameur F (2000). Phenological phases of *Argania spinosa* (L. Skeels) flower. Forest Genetics 7:333-338.

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

Bani-Aameur F (2002a). *Argania spinosa* (L.) Skeels flowering phenology. Genetic Resources Crop Evolution 49:11-19.

Bani-Aameur F, Benlahbil S (2004). Variation in RAPD markers of *Argania spinosa* trees and their progenies. Forest Genetics 11(3-4):337-342.

Benlahbil S, Bani-Aameur F (1999). Pollination of the argan tree is mostly entomophilous. In: Symposium of international plant resources: Argan and plants in arid and semi-arid areas. Faculty of Sciences, Agadir 23-25 April: pp. 119-120.

Bernstein IH, Teng GK, Garbin CP (1988). Applied Multivariate Analysis. Springer-Verlag New York Berlin Heidelberg London Paris Tokyo, P. 508.

Cuni-Shanchez A, De Smedt S, Haq N, Samson R (2011). Variation in baobab seedling morphology and its implications for selecting superior planting material. Scientia Horticulturae 130:109-117.

Dagneli P (1984). Théorie et Méthodes Statistiques. Applications Agronomiques. Tome II, 2Ed. Les Presses Agronomiques A.S.B.L. de Gembloux (Belgique), 464 pages.

Dinis LT, Peixoto F, Pinto T, Costa R, Bennett RN, Gomes-Laranjo J (2011). Study of morphological and phenological diversity in chestnut trees ('Judia' variety) as a function of temperature sum. Environ. Exper. Bot. 70(2-3):110-120.

Ehrig FR (1974). The argan character, ecology and economic maintenance of a significant tertiary in Morocco. Ptermanns geographical releases, 118(2):117-125.

Ferradous A (1995). Genetic diversity of some morphological characters of fruit and kernel of the argan tree (*Argania spinosa* (L.) Skeels). Third cycle thesis of higher education, Faculty of Sciences, University Ibn Zohr. Agadir. 180p + appendices.

Ferradous A, Bani-Aameur F, Dupuis P (1996). Stationnel climate, phenology and fruiting of the argan tree. Act. Inst. Agron. Vet. Hassan II. 17(1):51-60.

Frontier S (1981). Statistical Methods. Applied to Biology, Medicine and Ecology. Eds Masson, Paris, New York, Barcelona, Milan. P. 246.

Jamnadass R, Lowe, AJ, Dawson I (2009). Molecular markers and the management of tropical trees: the case of indigenous fruits. Trop. Plant Biol. 2:1-12.

Maurin R (1992). Argan oil, *Argania spinosa* (L.) Skeels Sapotaceae. French Rev. Fatty Substances 56:139-146.

Malvolti ME, Fineschi S, Pigliucci M (1994). Morphological integration and genetic variability in *Juglans regia* L. J. Heredity 85:389-394.

Metro A (1952). Preliminary observations on argan tree in Oued Cherrate and Dar Askraoui for genealogical selections. Ann. Forest. Rech. (Rabat), Annual Report: pp. 201-215.

M'hirit O (1989). Argan: a forest and fruit tree to multiple uses. Continuous Forest Formation, theme "argan". Forest Research Station. Rabat. 13-17 March. pp. 31-58.

Msanda F, El Aboudi A, Peltier JP (2005). Biodiversity and biogeography of the Moroccan argan tree. Cahiers Agricultures. 14(4):357-364.

Mückschel C, Otte A (2003). Morphometric parameters: an approach for the indication of environmental conditions on calcareous grassland. Agriculture, Ecosyst. Environ. 98(1-3):213-225.

Pfahler PL, Pereira MJ, Barnett RD (1996). Genetic and environmental variation in anther, pollen and pistil dimensions in sesame. Sex Plant Reprod. 9:228-232.

Prendergast HDV, Walker CC (1992). The argan: multipurpose tree of Morocco. The Kew Magazine. pp. 9:76-85.

Rahali M (1989). The production of argan forest. Continuous Forest Formation, theme "argan". Forest Research Station, Rabat, 13-17 March. pp. 31-58.

Rakonjac V, Akšić MF, Nikolić D, Milatović D, Čolić S (2010). Morphological characterization of 'Oblačinska' sour cherry by multivariate analysis. Scientia Horticulturae 125(4):679-684.

Rohlf FJ (1988). NTSYS-pc Numerical Taxonomy and Multivariate Analysis System. Version 1.80 Exeter Publ., Ltd, Setauket, New York.

Sandret F (1957). The argan pulp: Chemical composition and fodder value, change during maturation. Ann. For. Rech. (Rabat) 4:153-177.

Simbo DJ, De Smedt S, Den Bilcke NV, De Meullenaer B, Camp JV, Uytterhoeven V, Tack F, Samson R (2012). Opportunities for domesticating the African baobab (*Adonsonia digitata* L.): multi-trait fruit selection. Agroforest Syst, DOI: 10.1007/s10457-012-9568-7.

Sokal RR, Rohlf FJ (1995). Biometry, the Principales and Practice of Statistics in Biological Research. 3Ed. W. H. Freeman and Company New York. P. 887.

Steel RGD, Torrie JH (1960). Principles and Procedures of Statistics. 1Ed. McGraw-Hill Book Company, Inc. New York Toronto London. P. 481.

Sultan SE (2000). Phenotypic plasticity for plant development, function and life history. Plant Sci. 5(12):537-542.

Tworkoski TJ, Glenn DM (2010). Long-term effects of managed grass competition and two pruning methods on growth and yield of peach

trees. Scientia Horticulturae 126(2):130-137.
Zahidi A, Bani Aameur F, Dupuis P (1995). Characterization of branching of the argan tree. Acts of International Symposium: Forest Facing Desertification: the case of argan. Faculty of Sciences Agadir:pp. pp. 36-52.
Zahidi A (1997). Phenology, typology and genetic variability of branching and foliation traits *Argania spinosa* (L.) Skeels. Third cycle thesis, Faculty of Sciences, University Ibn Zohr. Agadir. 177p + appendices.
Zahidi A, Bani-Aameur F (1999a). Leaf phenology of *Argania spinosa*. In: Symposium of international plant resources: Argan and plants in arid and semi-arid areas. Faculty of Sciences, Agadir 23-25 April: pp. 173-176.
Zahidi A, Bani-Aameur F (1999b). Phenology of branching in argan tree. In: Symposium of international plant resources: Argan and plants in arid and semi-arid areas. Faculty of Sciences, Agadir 23-25 April: pp. 177-179.
Zahidi A (2004). Genetic diversity of leaf, growth and branching of stem and root in *Argana spinosa* (L.) Skeels seedlings. Doctorate Thesis. Faculty of Sciences, University Ibn Zohr. 180p + appendices.
Zunzunegui M, Ain-Lhout F, Jáuregui J, Díaz Barradas MC, Boutaleb S, Álvarez-Cansino L, Esquivias MP (2010). Fruit production under different environmental and management conditions of argan, *Argania spinosa* (L.) Skeels. J. Arid Environ. 74:1138-1145.