Available online at www.ijpab.com

ISSN: 2320 – 7051
Int. J. Pure App. Biosci. **2 (1):** 86-105 (2014)

Research Article

International Journal of Pure & Applied Bioscience

Variability in the productivity of fruits and oil in three natural populations of *Argania spinosa* L. Skeels: combined effects of environment and genotype

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ABSTRACT

With the aim to determine the effects of genotype and environment on the productivity of fruits and oil, a field study was carried out during five consecutive seasons in three natural populations of Argania spinosa from three geographical origin; Ait Melloul, Argana and Ait Baha in south west Morocco. The yield corresponding to total production in fruit per tree is highly correlated to the estimated yield by the sampling method. The regression coefficient (R^2) is 0.73. Fruits productivity was varied between 0.1 Kg (65.9 fruits) in the 1st season in Ait Baha to 94.4 kg (29298.2 fruits) during the 3rd season in Argana. For the other components of fruit, values varied from 0.8 kg to 6.2 kg in Ait Melloul, from 0.9 kg to 7.9 kg in Argana for almonds and kernels; and between 0.13 kg to 3.7 kg for almonds and hulls in Ait Baha. Frequency of fruiting trees in the 1st season was higher in Argana (93.3%) and Ait Melloul (86.7%) than in Ait Baha (50%). It was very low during the 5th season (16.6%) in Argana, in the 3th (30%) season in Ait Baha. Oil content in almonds varied from 39.2% to 44.1%, but estimated annual yield of argan oil varied from 0.1 kg to 2.6 kg / tree. Seasonal variations, geographical origin and genotype influence the index qualitative of argan oil by modifying only the refractive index but not the percentage of free fatty acids. Some genotypes were able to produce more fruits and almonds during four seasons which shows the potential of genetic diversity present in the argan tree. To cope with water scarcity in flowering and fruit ripening seasons in argan ecosystems, it is necessary to develop an irrigation system in orchards coupled with a choice of "plus" genotypes to ensure high yields of fruit and oil.

Keywords: *Variability, genotype, total production, regression, oil, fruit, environment, estimated yield.*

INTRODUCTION

Fruit trees have the potential to contribute towards food security, nutritional health and income generation and mitigate environmental degradation in developing countries[1,2,3]. Plant growth and productivity are constrained 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 Morocco, able to provide a diversity of resources that are the basis of economy for the local population[4]. This wild tree native to south west Morocco subjected to a constant regression due to over-exploitation, plays essential local ecological and economical roles[5]. Nineteen percent of the local population incomes depend of this tree[6,7]. The woodlands, though open, protect the soil against erosion and desertification, they shade different types of crops, and they help maintain soil fertility in an arid climate. Wood is used for carpentry and fuel. Seeds are used for oil production, with nutritional, medicinal and cosmetic purposes. Leaves, as elevated grasslands, are browsed by livestock, mainly goats, but also camels[8]. At the present time, several physical and anthropogenic factors reduced the density and area of Argan ecosystems, so it decreases the biodiversity in the arganeraie ecosystem. Due to the continuous intensify of genetic erosion, it is necessary to save situation of this species[7,9]. Recent interest for its conservation and development increased following UNESCO declaration of argan area of distribution a MAB (Man & Biosphere) Reserve of Biosphere[10]. The fruit is the main product, from its kernels, the prised oil is extracted. However, few studies have focused on productivity of fruit, oil and the annual yield of trees in different localities. The flowering-fruiting cycle in argan is spread from 9 to 16 months depending on the trees. Precocious trees which produce fruit in March, belated trees bearing the fruits in June and the intermediate trees which bear the precocious and belated fruits[11]. The fruiting of trees depends on seasonal variations prevailing during the flowering and fruit growth period. Water availability affects fruiting but 100 mm of rainfall in autumn of fruit maturation is sufficient to achieve optimal production of fruits. Productivity of the argan tree estimated by the frequency of fruitful trees, the fruit weight, kernel and pulp varies according to seasonal variations and tree[12]. 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[13].

Fruit yield is estimated from 450 to 500 kg / ha / season[14,15]. In an orchard trees, grown for seven seasons and irrigated in two sites in the Negev desert of Israel, fruit yield varied between 1.4 kg and 20.2 kg in Keturah and between 0.5 kg and 24.1 kg in Ramat Negev[16]. Similar results were obtained with ten trees in the field observed individually in Ait Melloul in south west Morocco. The fruit yield was ranged from 1.5 to 22.4 kg / season per tree[17,18]. Fruit yield is often estimated on a small number of trees without addressing the other components of fruit. Argan oil is now the most expensive edible oil in the world. The oil, which has been a mainstay for Berbers in southwestern Morocco for centuries, was propelled out of obscurity by favorable findings about its culinary, cosmetic and even medicinal virtues[19]. Argan oil is extracted by traditional method[20,21], by press or by chemical extraction[22]. The drying temperature of almonds and duration in chemical extraction are rarely reported, it is 60 ° C for three hours[23] or 40 ° C without indication[24,25]. The organic solvent used is Hexane[24,25,23] or more rarely Petroleum Ether[26,16]. The mixture of fruit samples harvested from different geographical origins and sometimes from many trees in a single region in several seasons can have an overall estimate of oil yield and therefore the comparison of different studies was not possible. The purpose of this study was to determine to what extent the fruit yield, oil yield and various components of fruit in argan were affected by tree genotype, seasonal variations in temperature and rainfalls during five consecutive seasons in three natural populations; Ait Melloul Argana and Ait Baha in south west Morocco.

MATERIALS AND METHODS

Plant material and measurements

Yield estimates

The spiny nature of Argan makes fruit picking directly from trees hard, thus fruits are collected accumulated under the trees' canopy after senescence or the drop. The harvest of senescent fruits in each tree remains the only method for estimating fruit yield. In this sense, two square frames of 0.25 m² each, one to the north and the other facing south, were filed under eight randomly selected trees in Ait Melloul site for one season. The fallen fruit in the two frames were harvested and dried in the open air. Fruit weight (g/0.25m²) was measured and the estimated yield was calculated by the formula:

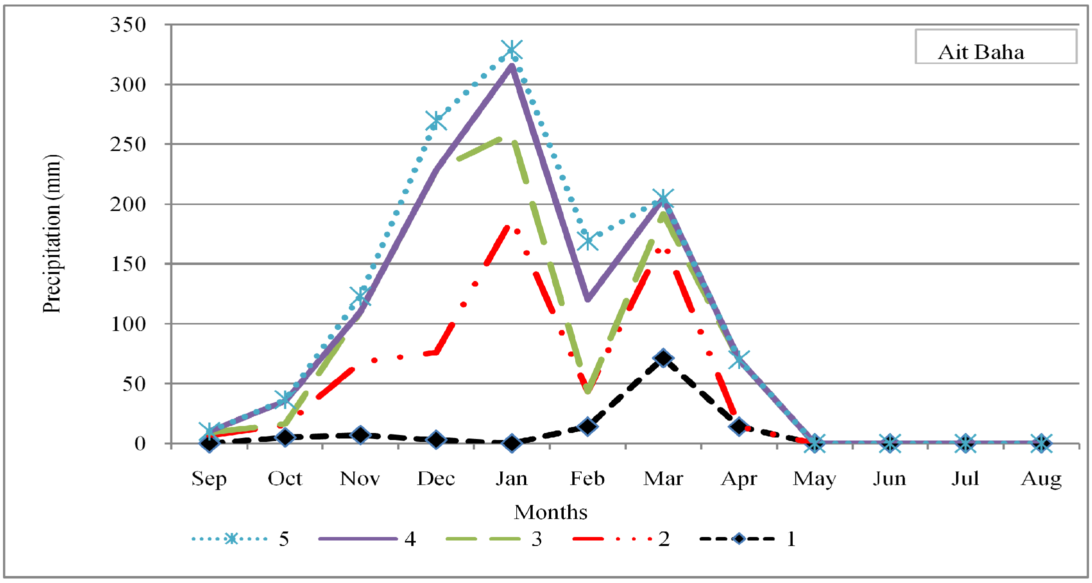
$$\boxed{\mathbf{R\ (kg) = (X / 0.25)\ x\ S}}$$

Whereas, X = mean of the total weight of fallen fruit in the two frames. S = the estimated surface for an ellipse by the projection on the ground of the crown (m²). S = D x d x π (D: large diameter, d: small diameter, π = 3.14). 0.25 = surface (m²) of each frame.

The yield variability

On the basis of the previous observations, with the aims to study the yield variability of fruit and his components, this research was conducted during five consecutive seasons in three natural populations i.e. Ait Melloul (latitude: 30° 20' N, longitude: 9° 29' W, altitude: 32 m), Argana (latitude: 30° 78' N, longitude: -9° 11' W, altitude: 620) and Ait Baha (latitude: 34° 21' N, longitude: 5° 33' E, altitude: 550) located in south west Morocco. Rainfalls during the five seasons of study were often scarce and variable, taking place mainly during the cold period while summer was dry (Figure 1).

Figure 1: Monthly rainfall (mm) recorded during the five seasons compared to the average of 16 years



Thirty randomly selected trees in each of the three geographical origins that have been subject to previous studies for the characters of phenology, branching, leaf, fruit, flower and pollen[12,18,10,27,28] were observed. The two square frames of 0.25 m² each, one to the north and the other facing south, were filed under each genotype (tree / locality). The fallen fruit in the two frames were harvested and dried in the open air. Six characters were investigated: total fruit weight (PT) (g/m²), fruits number (NF), kernels weight (PN), pulps weight (PPU), hulls weight (PC) and almonds weight (PA).

+ The frequency of fruiting trees in each site is calculated as follow:

$$\boxed{\% = \text{Number of fruiting trees} \times 100 / 30}$$

+ Annual yields of fruits, pulps, kernels, hulls and almonds are calculated for each tree by the formula:

$$\boxed{\text{Yield (kg)} = (X / 0.25) \times S / 1000}$$

Whereas, X = the total weight of fruit, kernel, pulp, hull and almonds. S = the estimated surface for an ellipse by the projection on the ground of the crown (m²). S = D x d x π (D: large diameter, d: small diameter π = 3.14).

+ The estimated total number of fruits is calculated by the formula:

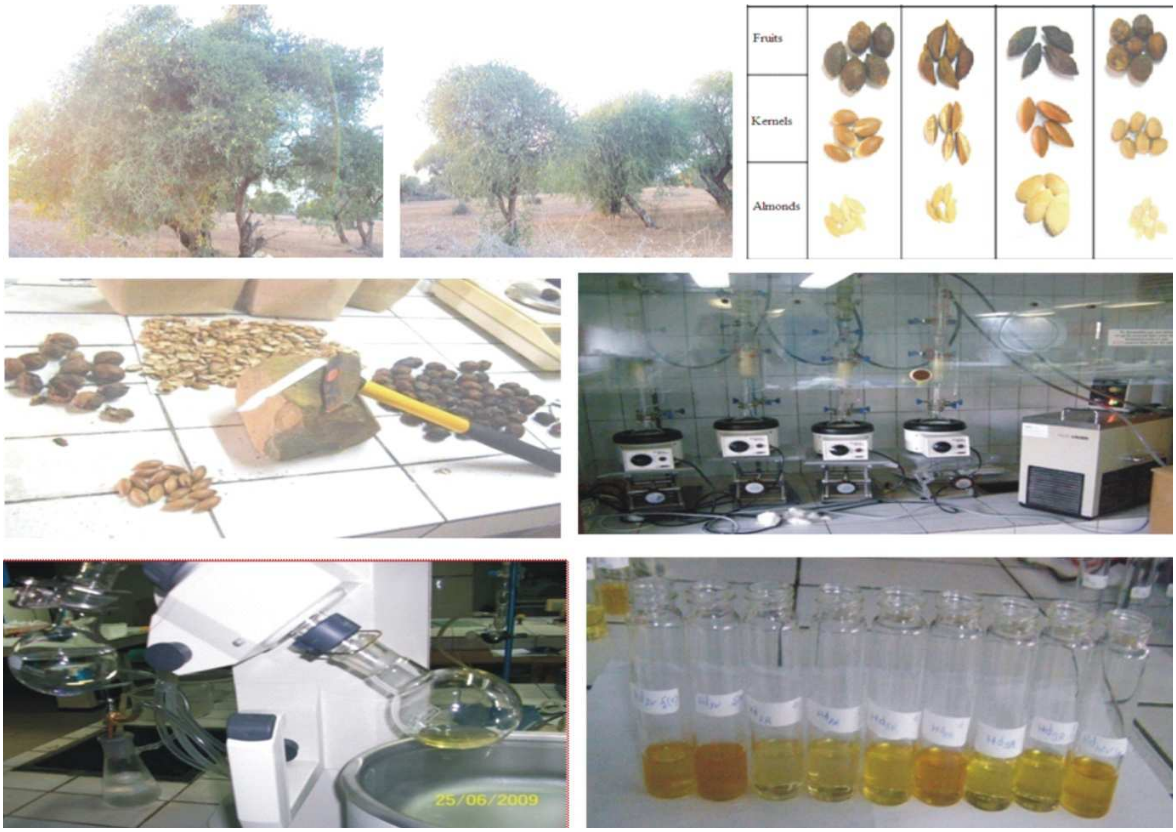
$$\boxed{N = (n / 0.25) \times S}$$

Whereas n = total number of fruits collected in the two frames.

Oil yield and percentage of various fruit components

The fruiting in argan differs depending on seasons and trees. Some trees can produce fruit during one, two, three, four and/or five seasons. Others trees have borne fruits in only one season. For analysis of oil yield and other fruit components over two seasons (4th and 5th season), three trees per group were selected: four groups (I, II, III and IV) from Ait Melloul, one group from Argana (V) and the other one originated of Ait Baha (VI). Ten grams of almonds per tree were dried in an oven at 60 °C for 3 hours. A millbase of almonds thus torrefied was placed in filter of Soxhlet (Figure 2). Oil extraction was carried out by chemical method with hexane (soxhlet) which takes about six hours, six extraction cycles (Figure 2). A volume of 150 ml of Hexane (69 ° evaporation point) as an organic solvent was used. At the end of the last cycle of extraction, argan oil soluble in the solvent was recovered after evaporation of hexane in a rotavapor. The oil extracted was weighed in grams and then stored in the dark under vacuum at -20 ° C.

Figure 2: Oil extraction by chemical method using hexane (soxhlet) and fruit components



+ The percentage of kernels, pulps, hulls, almonds or oil content is calculated by the formula:

$$\% = (\text{Weight of X / total dry weight of fruit}) \times 100$$

Whereas, X is the weight of kernels, pulps, hulls, almonds or oil content.
To study the quality of argan oil, two parameters were observed i.e. the refractive index and free fatty acids. The refractive index was measured by an Abbe Refractometer 1T, 4T [39]. For free fatty acids, 1g of argan oil was weighed in a beaker to which is added 7.1 ml of Ethanol 95%, 0.28 ml of Phenolphthalein 1% and a few drops of NaOH 0.1N for neutralization. The solution was placed in the dark for 1 min, stirred continuously and was titrated with NaOH 0.25N until obtaining a permanent pink coloration that persists for at least one minute[39].
+ Percentage of free fatty acids was calculated as:

$$\% \text{ free fatty acids} = V \times 7.05$$

Whereas, V = volume of NaOH 0.25N added.

$$\text{Acid index} = \% \text{ free fatty acids} \times 1.99$$

Statistical analysis

A regression of the weight of fruit harvested in the two frames as a function of total production, in addition, a correlation of the total production and the estimated yield of each tree have been adopted in order to estimate fruit yield in argan tree.

An analysis of variance (ANOVA) with three factors (seasonal variations, locality and genotype (tree/locality) in hierarchical model was adopted. Seasonal variations and locality were crossed. Tree was hierarchical to locality since trees are not repeated within the same locality and between sites[29]. Data were transformed to *arc sin [(x + 5)/100]1/2* before being submitted to the ANOVA. The Least Significant Difference Test (LSD α = 5 %) of equality of means was used to compare differences between means[30,31,32]. The analysis is performed using Statistix, Statitcf, NTCYS-pc package of computer programs[33].

RESULTS

Yield estimates

For eight randomly selected trees, total weight of fruits harvested in one season, in the two frames was about 117.85 g / 0.25 m² in average ranging from 295.1g / 0.25 m² and 42.2g / 0.25 m² (Table 1). The regression equation revealed that total weight of fruits harvested in the two frames was highly correlated with the total production of trees bearing fruits since regression coefficient (R^2) was about 0.61(Figure 3). The total production per tree was about 4.9 kg on average ranging from 11.1 kg and 1.6 kg (Table 1). The fruit yield which represents the total production of fruit by trees was highly correlated to yield estimated by the sampling method, since regression coefficient (R^2) was 0.73 (Figure 4). Estimated yield was about 12.7 kg in average and was ranged from 4.7 kg and 21.9 kg (Table 1).

Table 1 : Total fruit weight (g / 0.25m ²) harvested in the two frames, tree surface (m²), estimated yield (kg) and total production (kg) of eight trees in the field in one season

Tree	Fruit weight (g/0.25m²)	Tree surface (m²)	Estimated yield (kg)	Total production (kg)
1	**295,1**	18,53	**21.9**	**11.1**
2	119,85	36,48	14.9	3.4
3	137,43	20,34	19.7	5.9
4	62,07	17,56	8.6	5.3
5	91,48	36,1	9.3	2.1
6	141,87	23,3	15.4	2.9
7	**42,2**	24,44	**4.7**	2
8	52,8	12,99	7.4	**1.6**
Average	**117.85**	23.7	12.7	**4.9**

Figure 3: Regression line between the fruit weight of both samples and the total production observed in eigth trees in the field

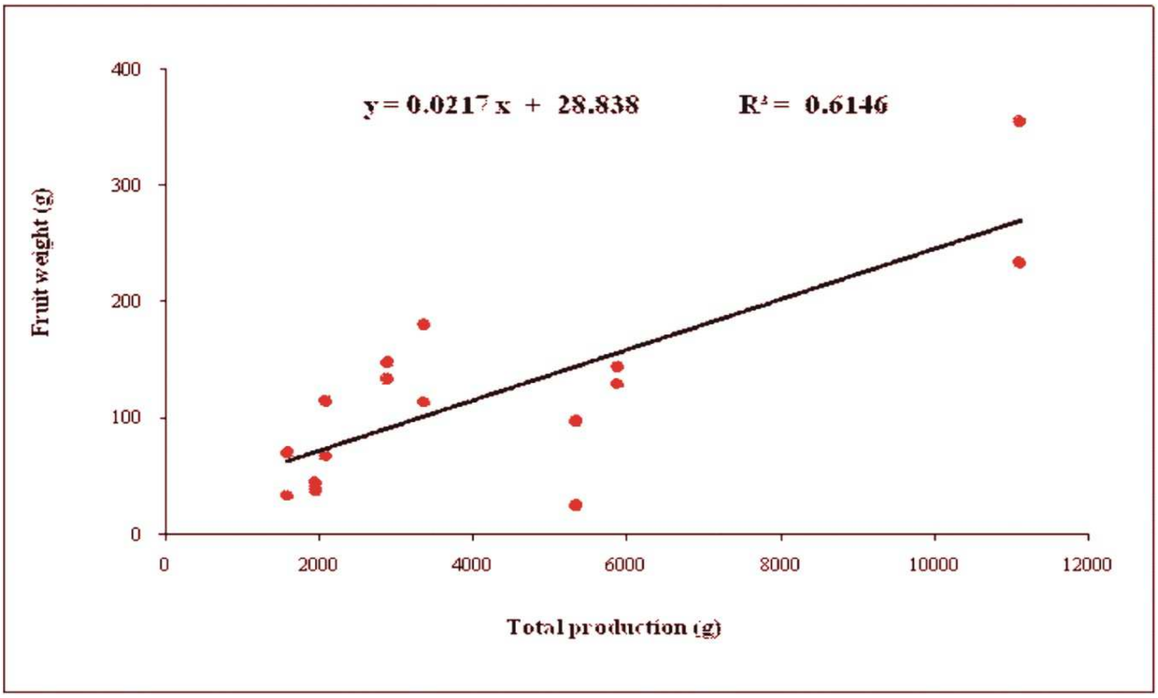
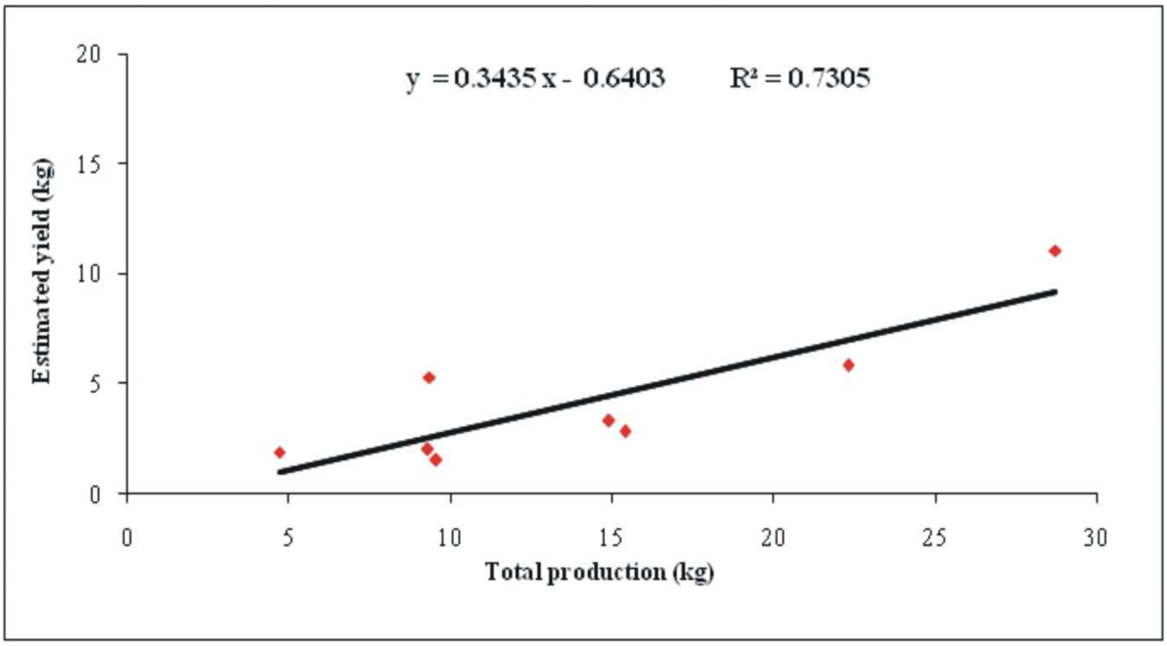


Figure 4: Regression line between the estimated yield (kg) and the total production (kg) observed in eight trees in the field

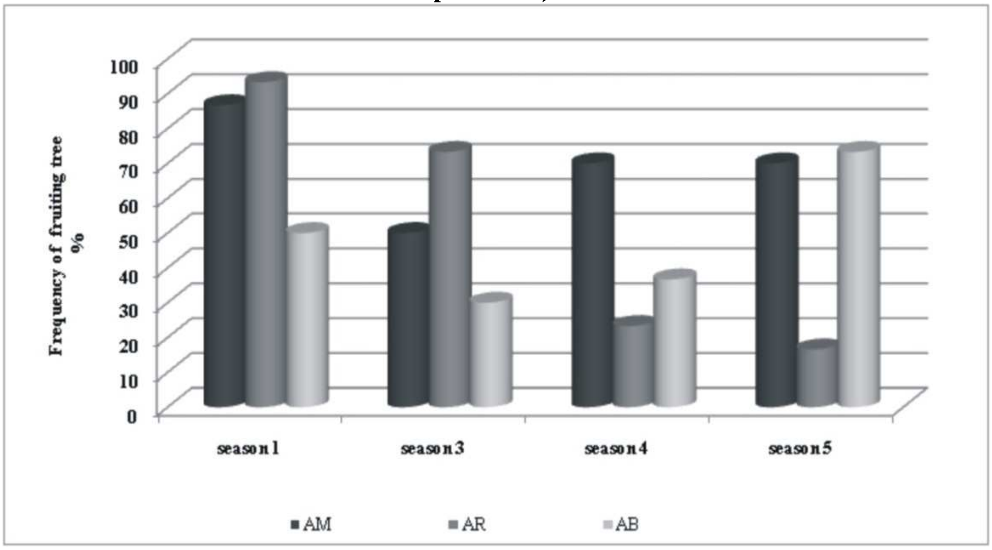


The yield variability

Frequency of fruiting trees

The frequency of fruiting trees in the 2nd season was negligible, and was not presented here. It was a result of very low rainfall recorded during the season of flower production (1st season). Frequency of fruiting trees in the 1st season was higher in Argana (93.3%) and Ait Melloul (86.7%) than in Ait Baha (50%). It was very low during the 4th season (23.3%) and the 5th season (16.6%) in Argana, in the 3th (30%) and the 4th (36%) seasons in Ait Baha site (Figure 5).

Figure 5: Frequency of the fruiting trees for five seasons in Ait Melloul, Argana and Ait Baha. (Season 2: not presented)



Fruit yield and fruit components

Influence of locality and seasonal variations

Locality and seasonal variations were not significant for all characters, but environment effect expressed by locality x seasonal variations interaction was highly significant for all traits (Table 2). In general, in Argana and Ait Melloul, during the 4th season, low values of all traits were recorded. But in Ait Baha site, low productivity of fruits and their components was recorded in the 1st season (Table 3). For thirty trees per site, annual averages of yields of fruits, kernels, pulps, hulls, almonds and fruits number were higher in Ait Melloul during the 1st, 3rd, 5th seasons; but very low in the 4th season (Table 3). Yields of different components of fruit in fruiting trees were more important during the 1st and the 2nd season in Argana and during the 3th and the 5th season in Ait Baha site. For all trees, fruits productivity was varied between 0.1 Kg (65.9 fruits) in the 1st season in Ait Baha to 94.4 kg (29298.2 fruits) during the 3rd season in Argana. In Ait Melloul site, yield was ranged from 55.8 kg (23594.5 fruits) in the 3rd season and 1.8 kg (904.2 fruits) in the 1st season. For the other components of fruit, values varied from 0.8 kg to 6.2 kg in Ait Melloul, from 0.9 kg to 7.9 kg at Argana for almonds and kernels; and between 0.13 kg to 3.7 kg for almonds and hulls in Ait Baha.

Influence of genotype

Genotype (tree / locality) was not significant but genotype x environment interaction (tree x seasonal variation / locality) was highly significant for all traits which emphasizes the individual response of each genotype to seasonal variations of rainfall in each site (Table 2).

Table 2: Analysis of variance of six characters observed during four consecutive seasons in Ait Melloul, Argana and Ait Baha

Source of variation	DF	Mean square					
		NF	PT PN	PPU	PA		PC
Locality	2	68471 ns	286490 ns	116990 ns	70572 ns	1580 ns	91486 ns
Seasonal variation	3	8717.5 ns	54018 ns	20797 ns	16370 ns	313.75 ns	16248 ns
Locality x seasonal variation	6	7456.1 **	73545 **	26944 **	25386 **	312.43 **	21619 **
Tree / locality	87	1619.6 ns	13947 ns	6177.1 ns	8232.7 ns	81.39 ns	5071.9 ns
Tree / locality x seasonal variation	261	1193.6 **	10052 **	4254 **	6041.2 **	58.81 **	3524.8 **
Error	360	314.71	1858.1	638.6	363.87	19.28	502.8

DL: degree of freedom, ns: not significant, **: significant at 1%.

Table 3: Maximum, minimum and average in kg / tree of fruits number (NF), total fruit weight (PT), kernels weight (PN), pulps weight (PPU), hulls weight (PC) and almonds weight (PA) in Ait Melloul (AM) , Argana (AR) and Ait Baha (AB) for four seasons

Characters		Ait Melloul					Argana					Ait Baha				
		1	3	4	5	**Average**	1	3	4	5	**Average**	1	3	4	5	**Average**
NF	Average	**4022.9**	3950.5	2313.9	3449.1	**3434.10**	5424.1	8545.6	590.5	1230.6	**3947.70**	469.5	3093.6	1554.6	2894.4	**2003.03**
	Maximum	19742.3	23594.5	13001	12073.6		42700	**29298.2**	6412.4	16071.8		2160.4	21881.6	7806.5	12970.8	
	Minimum	904.2	1898.6	667.3	1034.3		734.6	1360.5	244.1	2468.5		**65.9**	917.8	339.1	558.4	
PT	Average	**12.1**	**9.8**	**7.4**	**10.7**	**10.00**	**19**	**27.5**	**2.3**	**4.4**	**13.30**	**1.1**	**7.2**	**5.3**	**9.2**	**5.70**
	Maximum	43.4	55.8	29.2	43.2		70.8	94.4	25.8	50.1		6.3	34.3	35.4	53.2	
	Minimum	1.8	3.4	2	3.4		0.2	4	0.9	11.3		0.1	2.6	1.2	1.9	
PN	Average	**6.4**	**6.5**	**4.7**	**7.1**	**6.18**	**11.4**	**16.5**	**1.5**	**2.3**	**7.93**	**0.6**	**4.7**	**3.4**	**5.9**	**3.65**
	Maximum	25.2	36.1	18.1	27.8		45	60.4	17.7	26		3.6	21.3	21.8	29.3	
	Minimum	1	1.7	1	2.3		0.1	2.5	0.6	6.6		0.1	1.3	0.7	1.2	
PPU	Average	**2.53**	**3.4**	**2.7**	**3.7**	**3.08**	**7.1**	**11**	**0.7**	**2**	**5.20**	**0.4**	**0.6**	**0.8**	**0.98**	**0.70**
	Maximum	15.4	19.7	11.1	15.3		17.9	48.1	8.1	24.1		2.7	7.3645	5.0487	3.9787	
	Minimum	0.8	2.9	0.8	0.9		2.8	1.5	0.3	4.7		0.03	0.5	0.9	0.1	
PA	Average	0.9	0.8	0.6	0.8	**0.78**	1.14	1.9	0.2	0.3	**0.89**	0.1	0.1	0.1	0.2	**0.13**
	Maximum	3.6	4.3	2.5	4.1		3.4	6.2	1.4	3		0.4	1.9	0.6	0.8	
	Minimum	0.1	0.4	0.1	0.1		1.2	0.3	0.1	0.7		0.01	0.1	0.2	0.1	
PC	Average	6.2	6	4.2	6.3	**5.68**	9.6	14.7	1.3	2.1	**6.93**	0.6	0.5	1.4	1.9	**1.10**
	Maximum	24	31.8	15.6	23.7		31.1	54.2	16.7	23		3.2	5.9	10.7	8.5	
	Minimum	1	2.9	0.9	1.2		9.5	2.2	2.2	6		0.03	0.3	0.9	0.1	

Some genotypes from Ait Melloul, Argana and Ait Baha can produce fruit during two, three or four seasons (Table 4). While a relatively small number of trees especially in Ait Baha, the driest site, did not produce fruit or had borne fruits in only one season. Although the trees were fruitful, number of fruit produced is variable depending on the station. Genotypes (12, 17 and 24) from Ait Melloul were able to produce more fruits and almonds since the number of fruits was between 10362.6 and 23594.5, the fruit weight varied between 21.6 kg and 55.8 kg and almond weight between 2 kg and 4.3 kg during the 1st and 3rd seasons of high productivity (Table 5a). Yield of the other components of fruit was ranged between 7.5 for pulps weight and 23.3 kg hulls weight. In addition, these genotypes can produce fruits even in season of low productivity (4th), since yield can reach 29.2 kg (13001 fruits) for fruits and 2.5 kg for almonds.

Genotypes (2, 13, 26 and 29) from Argana were also able to produce more fruits and almonds since the number of fruits was between 15626.2 and 29298.2 kg, the yield varied between 40.6 kg and 94.4 kg for fruits and from 3.7 kg and 6.2 kg for almonds during the 3rd season of high productivity in this site (Table 5b). Yield of the other components of fruit was ranged between 5.1 for pulps weight and 27.1 kg for kernels weight. For these genotypes, in the 4th season of low productivity, the number of fruits was between 2587.2 and 13001, the fruit weight varied between 9.1 kg and 29.2 kg and almond weight between 0.74 kg and 2.5 kg. Genotypes (12, 23 and 25) originated from the driest station Ait Baha, were able to produce fruits and almonds but of minor importance compared to the other two sites (Table 5c). Yields were between 23.03 kg and 33.72 kg for fruits and between 1.12 kg and 2.6 kg for almonds even in years of high productivity in this site (4th and 5th seasons).

Table 4 : Trees that produced fruits during 1, 2; 3 and 4 seasons in Ait Melloul, Argana and Ait Baha

	Ait Melloul	Argana	Ait Baha
Four seasons	1; 2; 3; 4; 12; 17; 20; 23 and 24 (**30%**)	8 (**3.3%**)	1; 8 and 30 (**10%**)
Three seasons	5; 6; 9; 11; 13; 14; 18; 19; 25;26 and 28 (**36.7%**)	7; 12; 13 and 20 (**13.3%**)	4; 9; 10; 17; 22; 24; 25; 27 and 28 (**30%**)
Two seasons	7; 10; 21; 22; 29 and 30 (**20%**)	1; 2; 3; 5; 6; 9; 11; 14; 15; 16; 17; 19; 21; 22; 24; 25; 26; 27; 28; 29 and 30 (**70%**)	2; 3; 11; 13; 14; 16; 18; 19 ; 21; 23 and 29 (**36.7%**)
One season	16 and 27 (**6.7%**)	4; 10; 18 and 23 (**13.3%**)	5; 6; 7; 12; 15; 20 and 26 (**23.3%**)
No season	8 and 15 (**6.7%**)	-	-

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Table 5a: Annual yield of fruit number (NF), fruits weight (PT) in kernels (PN), pulps (PPU), almonds (PA), hulls weight (PC) of the thirty trees from Ait Melloul during the four seasons

Trees	Ait Melloul																							
	NF				**PT**				**PN**				**PPU**				**PA**				**PC**			
	1	3	4	5	1	3	4	5	1	3	4	5	1	3	4	5	1	3	4	5	1	3	4	5
1	2669.1	5268	2107.2	1404.8	11.7	**24.9**	9	4.3	7.1	16.8	6.03	3.4	4.6	8.2	2.9	0.9	0.9	1	0.52	0.4	6.2	15.8	5.52	3
2	948.5	16926.7	2553.6	10287.4	22.7	31.1	5.32	24.1	12.7	20.5	5.32	16.2	6	10.6	5.32	7.9	2.3	2.2	5.32	1.3	10.4	18.2	5.32	14.9
3	9553	9786	699	1584.4	43.1	**75.1**	5.8	7.7	25.2	56.5	4.1	4.9	18	18.6	1.7	2.8	2.2	3.3	0.24	1.3	22.9	**53.2**	3.83	3.7
4	1878.2	7801.9	4695.6	7801.9	8.7	16	21.3	32	5.2	11.3	13.1	17.6	3.6	4.8	8.2	14.4	0.6	2.2	1.75	3.8	4.6	9.1	11.4	13.8
5	1766.6	8313.6	701.5	0	3.7	13	2	0	1.8	7.1	1	0	1.8	5.9	1.01	0	0.2	1.1	0.11	0	1.6	6	0.9	0
6	723.4	0	2350.9	1989.2	1.9	0	8.1	6.6	1.1	0	5.1	4.1	0.8	0	3	2.6	0.1	0	0.6	0.4	1	0	4.6	3.7
7	1251.8	0	0	3775.1	2.3	0	0	7.7	1	0	0	5.2	1.1	0	0	2.5	0.1	0	0	0	1	0	0	5.2
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	1545.3	0	667.3	5162.6	6.4	0	3.5	27.1	3.1	0	2.3	24.4	3.3	0	1.3	2.7	0.3	0	0.2	0.9	2.7	0	2.1	23.5
10	2994.6	0	1140.8	0	7.8	0	4.41	0	5.5	0	2.6	0	2.2	0	1.8	0	0.6	0	0.32	0	4.9	0	2.3	0
11	904.2	0	1567.3	5545.8	3	0	4.45	17.2	1.2	0	2.5	9.5	1.8	0	2	7.8	0.2	0	0.4	1.1	1	0	2.1	8.3
12	**19742.3**	23594.5	13001	4454.1	39.3	**55.8**	29.2	9.1	19.4	36.1	18.1	5.6	20	19.7	11.1	3.4	3.6	4.3	2.5	0.7	15.9	31.8	15.6	4.9
13	7385.1	0	6653.9	5849.6	16	0	17.6	14.7	10.1	0	12.1	11	5.8	0	5.5	3.7	1.5	0	1.8	0	8.6	0	10.3	11
14	2644.2	0	2440.8	1586.5	12.8	0	**8.6**	4.7	5.5	0	8.2	2.8	7.2	0	8.2	2	0.8	0	0.82	0.8	4.7	0	5.2	2
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	2312.2	0	0	0	4	0	0	0	3.4	0	0	0	2.4	0	0	0	0.3	0	0	0	3.1	0	0	0
17	**10362.6**	2101.8	3714.9	8651.8	21.6	3.4	10.3	24.1	14.2	1.7	6.5	18.4	7.5	1.7	3.8	5.7	2	0.7	0.8	0.1	12.1	1	5.8	18.3
18	3644.8	0	2448	7180.8	11.1	0	12.2	25.6	5.7	0	9.1	12.3	5.4	0	3.1	13.3	0.9	0	1	2.2	4.8	0	8.1	10.1
19	0	5343.8	2643.2	1034.3	0	16	8.9	3.4	0	9	4.8	2.3	0	7.1	4.1	1.2	0	1	0.52	0.6	0	8	4.3	1.7
20	5714	11313.7	3657	1199.9	12.6	23.9	9.4	3.6	7.3	15	5.7	2.3	5.3	8.9	3.7	1.2	1	2.6	0.81	1.1	6.4	12.4	4.9	1.2
21	3460.6	0	1410.9	0	8.4	0	5	0	3.7	0	3.3	0	4.7	0	1.72	0	0.6	0	0.31	0	3	0	2.98	0
22	3087.8	0	0	3271.6	8	0	0	10.5	3.5	0	0	5.3	4.1	0	0	5.1	0.6	0	0	0.4	2.9	0	0	4.9
23	1148.9	2853.6	3743.1	5966.7	1.8	12.1	15.9	26.7	12.4	8.6	10.6	19.7	**7.4**	3.5	5.3	7	0.2	0.9	1.1	1	1.6	7.7	9.6	18.6
24	**11838.4**	6664	2587.2	12073.6	43.4	19	9.1	43.2	19.8	13	6.7	27.8	17.1	6	2.4	15.3	3	1.9	0.74	4.1	23.3	11.1	6	23.7
25	3218	1898.6	0	2767.5	12.8	6.2	0	7.8	2.2	3.3	0	4.5	4.6	2.9	0	3.3	0.8	0.4	0	0.5	7.4	2.9	0	4.1
26	2079.4	12692.8	0	8057.5	5.5	26.9	0	13.6	2.6	19.9	0	9.8	2.5	7	0	3.8	0.3	2.2	0	0.8	2.7	17.7	0	9
27	2676.4	0	0	0	7.2	0	0	0	12.9	0	0	0	3.5	0	0	0	0.5	0	0	0	3.2	0	0	0
28	14916	3955	8136	0	41.1	9.8	25.1	0	5.6	6.3	16.2	0	14.4	3.5	8.8	0	2.7	0.8	1.5	0	24	5.5	14.7	0
29	2220.5	0	2498	0	6.5	0	8.9	0	0	0	5.3	0	1.6	0	3.6	0	0.5	0	0.9	0	4.4	0	4.5	0
30	0	3800.7	0	3826.6	0	14.5	0	7.5	0	10.1	0	4.5	0	4.43	0	3	0	1.3	0	0.9	0	8.6	0	3.6

Table 5b: Annual yield of fruit number (NF), fruits weight (PT) in kernels (PN), pulps (PPU), almonds (PA), hulls weight (PC) of the thirty trees from Argana during the four seasons

Trees	Argana																							
	NF				**PT**				**PN**				**PPU**				**PA**				**PC**			
	1	3	4	5	1	3	4	5	1	3	4	5	1	3	4	5	1	3	4	5	1	3	4	5
1	2261.01	7416.1	0	0	7.44	24.8	0	0	4.94	16.41	0.00	0	2.50	8.4	0	0	0.48	1.8	0	0	4.46	14.6	0	0
2	4893.72	**16939.8**	0	0	20.99	51.8	0	0	11.95	27.35	0.00	0	9.04	24.4	0	0	1.66	3.7	0	0	10.29	23.7	0	0
3	1881.90	0	6412.4	0	5.37	0	25.8	0	2.68	0.00	17.75	0	2.68	0	8.1	0	0.30	0	1	0	2.38	0	16.7	0
4	0.00	1360.5	0	0	0.00	4.01	0	0	0.00	2.49	0.00	0	0.00	1.52	0	0	0.00	0.3	0	0	0.00	2.2	0	0
5	6725.97	9685.4	0	0	24.95	38.7	0	0	12.89	23.35	0.00	0	12.06	15.4	0	0	1.65	2.3	0	0	11.24	21	0	0
6	6961.50	0	0	8774	18.06	0	0	37.7	11.52	0.00	0.00	21	6.54	0	0	16.7	1.59	0	0	2.6	9.92	0	0	18.4
7	3614.60	0	2027.7	2468.5	6.41	0	8.4	11.3	4.20	0.00	5.99	6.6	2.21	0	2.4	4.7	0.57	0	0.6	0.7	3.63	0	5.4	6
8	3797.59	7405.3	1519	5696.4	1.71	31.4	7.6	19.3	0.33	21.61	5.30	9.5	0.14	9.82	2.3	9.8	0.08	1	0.4	1.3	0.07	20.6	4.9	8.2
9	2204.01	4231.7	0	0	1.76	16.8	0	0	0.76	10.72	0	0	0.41	6.1	0	0	0.35	1.1	0	0	0.03	9.7	0	0
10	1932.00	0	0	0	4.30	0	0	0	2.31	0.00	0	0	1.99	0	0	0	0.18	0	0	0	2.13	0	0	0
11	2611.00	9325	0	0	8.37	26.2	0	0	4.36	14.77	0	0	4.01	11.43	0	0	0.34	1.7	0	0	4.02	13.1	0	0
12	5899.74	5696.3	0	16071.8	8.95	13.4	0	50.1	4.74	6.63	0	26	4.21	6.74	0	24.1	0.65	0.9	0	3	4.09	5.7	0	23
13	9155.98	15626.2	0	3906.6	26.93	40.6	0	12.2	17.14	27.05	0	7.1	9.79	13.5	0	5.1	1.50	3	0	1	15.64	24.1	0	6.1
14	4521.59	21025.4	0	0	11.05	85.9	0	0	5.99	54.98	0	0	5.06	30.8	0	0	0.45	4.7	0	0	5.54	50.3	0	0
15	1627.67	5561.2	0	0	5.82	16	0	0	3.88	10.30	0	0	1.94	5.7	0	0	0.46	1.4	0	0	3.42	8.9	0	0
16	2708.60	6164.4	0	0	5.08	17.2	0	0	2.65	11.96	0	0	2.43	5.2	0	0	0.46	1.3	0	0	2.19	10.7	0	0
17	8976.84	8568.8	0	0	25.85	32.9	0	0	15.95	21.83	0	0	9.91	11.14	0	0	2.02	1.9	0	0	13.93	19.9	0	0
18	952.00	0	0	0	0.90	0	0	0	0.47	0.00	0	0	0.43	0	0	0	0.08	0	0	0	0.39	0	0	0
19	0.00	22078.2	4700.5	0	0.00	70.1	15.4	0	0.00	46.95	9.77	0	0.00	23.1	5.6	0	0.00	4.7	1.4	0	0.00	42.2	8.4	0
20	4270.00	10418.8	1708	0	4.69	29.9	5.5	0	2.45	18.28	3.16	0	2.25	11.5	2.3	0	0.43	2.6	0.5	0	2.02	15.7	2.6	0
21	991.80	0	1102	0	1.38	0	4.1	0	0.80	0.00	2.62	0	0.58	0	1.4	0	0.06	0	0.7	0	0.74	0	2.2	0
22	786.54	0	244.1	0	0.88	0	0.9	0	0.46	0.00	0.60	0	0.42	0	0.3	0	0.04	0	0.1	0	0.42	0	0	0
23	1704.00	0	0	0	4.69	0	0	0	2.52	0.00	0	0	2.17	0	0	0	0.19	0	0	0	2.33	0	0	0
24	791.19	2927.4	0	0	0.77	11.7	0	0	0.41	6.63	0	0	0.36	5.1	0	0	0.03	0.9	0	0	0.38	5.7	0	0
25	1780.00	2207.2	0	0	3.57	9.4	0	0	1.93	4.50	0	0	1.63	4.9	0	0	0.15	0.4	0	0	1.79	4	0	0
26	6646.09	20096.5	0	0	15.98	86.2	0	0	8.33	38.14	0	0	7.65	48.1	0	0	1.45	5.5	0	0	6.88	32.6	0	0
27	1008.28	14620.1	0	0	0.77	34.8	0	0	0.47	18.28	0	0	0.30	16.5	0	0	0.03	2.9	0	0	0.44	15.3	0	0
28	4804.20	21760.2	0	0	9.94	51.9	0	0	6.28	28.69	0	0	3.67	23.2	0	0	0.70	4.9	0	0	5.58	23.8	0	0
29	8748.77	29298.2	0	0	29.26	94.4	0	0	15.26	60.39	0	0	14.01	34.1	0	0	1.22	6.2	0	0	14.04	54.2	0	0
30	4936.89	13956.2	0	0	19.32	37.5	0	0	15.31	25.05	0	0	4.01	12.4	0	0	0.56	2.6	0	0	14.75	22.4	0	0

Table 5c: Annual yield of fruit number (NF), fruits weight (PT) in kernels (PN), pulps (PPU), almonds (PA), hulls weight (PC) of the thirty trees from Ait Baha during the four seasons

Trees	Ait Baha																							
	NF				PT				PN				PPU				PA				PC			
	1	3	4	5	1	3	4	5	1	3	4	5	1	3	4	5	1	3	4	5	1	3	4	5
1	96.5	836.3	1318.8	3313.1	0.14	0.51	8.25	11.75	0.08	2.85	5.19	6.50	0.05	3.06	4.2	5.25	0.006	0.355	0.654	0.628	0.076	2.495	4.538	5.871
2	949.2	0	791.0	0.0	0.85	0	0.62	0	0.50	0	2.06	0	0.35	0	2.06	0	0.060	0	0.007	0	0.437	0	0.2	0
3	0.0	791.3	0.0	863.2	0.00	2.14	0.00	1.64	0.00	1.19	0.0	1.21	0.00	0	0	0.43	0.000	0.159	0.0	0.136	0.000	1.027	0	1.071
4	2289.0	1297.1	0.0	1983.8	4.96	3.97	0.00	5.77	3.19	2.67	0.0	3.36	1.78	0.9	0	2.25	0.311	0.332	0.0	0.409	2.876	2.333	0	2.956
5	0.0	3908.2	0.0	0.0	0.0	**13.55**	0.0	0.0	0.0	**8.66**	0.0	0.0	0	**2.51**	0	0.00	0	**1.238**	0.0	0	0	7.422	0	0
6	0.0	3791.4	0.0	0.0	0.0	**13.01**	0.0	0.0	0.0	**7.62**	0.0	0.0	0	**2.2**	0	0.00	0	**0.620**	0.0	0	0	6.998	0	0
7	0.0	0.0	**4505.0**	0.0	0.0	0.00	**10.73**	0.0	0.0	0.00	6.26	0.0	0	0	4.4	0.00	0	0.000	0.713	0	0	0.000	5.550	0
8	495.6	4419.0	7103.4	2188.9	0.55	7.79	17.45	5.74	0.43	4.10	10.13	3.40	0.12	7.32	10.13	2.34	0.084	0.630	1.138	0.367	0.347	3.468	8.988	3.031
9	708.9	0.0	**6262.0**	**12642.2**	0.87	0.00	17.04	**33.72**	**0.52**	**0.00**	**8.55**	**20.79**	0.35	8.49	8.55	**12.93**	0.092	0.000	1.703	**2.559**	0.430	0.000	6.849	18.230
10	0.0	6069.6	674.4	337.2	0.00	23.66	2.53	1.20	0.0	16.48	1.22	0.96	0.00	1.31	1.22	0.24	0.000	1.583	0.185	0.087	0.000	14.894	1.035	0.877
11	0.0	0.0	2089.4	1641.7	0.0	0.0	7.42	3.35	0.0	0.0	3.95	2.10	0.00	3.46	3.95	1.26	0	0	0.624	0.184	0.000	0	3.331	1.967
12	0.0	0.0	5510.2	0.0	0.0	0.0	7.86	0.00	0.0	0.0	5.09	0.00	0.00	2.77	5.09	0.00	0	0	0.751	0.000	0.000	0	4.344	0.000
13	0.0	0.0	3119.5	127.3	0.0	0.0	8.96	0.27	0.0	0.0	5.83	0.16	0.00	3.13	5.83	0.12	0	0	0.824	0.026	0.000	0	5.006	0.130
14	0.0	0.0	1581.6	282.4	0.0	0.0	5.55	0.76	0.0	0.0	3.69	0.47	0.00	1.86	3.69	0.29	0	0	0.415	0.016	0.000	0	3.273	0.457
15	0.0	0.0	1226.8	0.0	0.0	0.0	5.71	0.00	0.0	0.0	4.08	0.00	0.00	1.63	4.08	0.00	0	0	0.294	0.000	0.000	0	3.787	0.000
16	0.0	0.0	2546.5	5220.3	0.0	0.0	11.89	11.67	0.0	0.0	8.51	7.69	0.00	3.38	8.51	3.97	0	0	0.628	0.705	0.000	0	7.883	6.987
17	1449.0	0.0	2790.7	4722.7	5.12	0.0	9.92	17.43	3.32	0.0	7.27	13.63	1.80	2.65	7.27	3.81	0.210	0	0.554	1.225	3.110	0	6.715	12.402
18	1127.0	0.0	0.0	2361.4	1.50	0.0	0.0	3.64	1.03	0.0	0.0	2.02	0.47	0.00	0.00	1.62	0.104	0	0	0.228	0.927	0	0	1.789
19	0.0	1524.9	0.0	2601.3	0.00	5.75	0.0	8.98	0.00	3.63	0.0	6.27	0.00	1.05	0	2.72	0.000	0.427	0	0.554	0	3.204	0	5.712
20	684.0	0.0	0.0	0.0	1.60	0.0	0.0	0.00	1.06	0.0	0.0	0.00	0.54	0	0	0.00	0.065	0	0	0.000	0.994	0	0	0.000
21	2407.9	0.0	0.0	2593.1	7.65	0.0	0.0	9.91	4.41	0.0	0.0	6.41	3.24	0	0	3.50	0.541	0	0	0.497	3.870	0	0	5.909
22	2948.0	0.0	2412.0	469.0	3.34	0.0	5.46	0.71	1.76	0.0	3.69	0.47	1.58	0	3.69	0.24	0.108	0	0.369	0.038	1.655	0	3.323	0.431
23	0.0	0.0	**12039.0**	**5688.8**	0.00	0.0	**28.80**	**11.01**	0	0	**19.65**	**8.39**	0	0	18.5	2.62	0.000	0	**1.904**	**0.706**	0.000	0	**17.748**	**7.682**
24	308.7	0.0	1852.0	1852.0	1.48	0.0	6.73	7.80	0.85	0.0	5.19	4.70	0.64	1.54	5.19	3.09	0.017	0	0.549	0.336	0.830	0	4.641	4.368
25	**4520.0**	0.0	**3955.0**	**6554.0**	8.78	0.0	14.39	23.03	**5.87**	**0.0**	**11.05**	**17.74**	**2.91**	**3.35**	**11.05**	**5.29**	**0.158**	**0**	**1.118**	**0.846**	**5.708**	**0**	**9.930**	**16.894**
26	0.0	0.0	0.0	4671.9	0.00	0.0	0.00	8.02	0.00	0.0	0.00	5.45	0.00	0.00	0.00	2.56	0.000	0	0.000	1.047	0.000	0	0.000	4.405
27	2305.2	0.0	2169.6	1695.0	4.28	0.0	10.71	3.33	2.43	0.0	6.85	2.36	1.85	3.86	6.85	0.97	0.127	0	0.393	0.147	2.302	0	6.458	2.208
28	2375.3	0.0	3934.1	890.7	7.52	0.0	20.76	8.23	3.87	0.0	13.90	6.37	3.64	6.86	13.90	1.85	0.227	0	0.664	0.435	3.645	0	13.236	5.939
29	0.0	1794.0	0.0	1242.0	0.00	8.10	0.00	5.07	0.0	5.60	0.00	3.01	0.00	0.00	0.00	2.06	0.000	0.490	0.000	0.105	0.000	5.112	0.000	2.904
30	1725.0	1275.0	3825.0	975.0	3.26	8.32	15.92	3.85	2.08	5.16	10.06	2.83	1.18	5.86	10.06	1.02	0.198	0.704	0.891	0.986	1.880	4.452	9.173	1.844

Oil yield and fruit components

Locality and seasonal variations

Locality and seasonal variations were not significant for % kernel, % pulp, % hull, % almonds, oil content / almonds weight and oil content / fruit dry weight (Table 6). Locality x seasonal variations interaction (environment effect) was significant for only oil content / fruit dry weight. The annual average of oil content / fruit dry weight was about 3.1% in the 4th season and 2.7% in the 5th season (Table 7).

Table 6: Analysis of variance for percentage of kernels (% K), pulps (% P), hulls (% H), almonds (% A), oil content / almonds weight (OCA) and oil content / fruit dry weight (OCF), refractive index and percentage of fatty free acid

Source of variation	DF	Mean square							
		% K / fruit dry weight	% P / fruit dry weight	% H / fruit dry weight	% A / fruit dry weight	OCA	OCF	Refractive index	Percentage of free fatty acids
Provenance (group)	5	172.03 ns	161.65 ns	190.53 ns	0.7 ns	157.65 ns	0.99 ns	6.7-05 **	2.03-01 ns
Seasonal variations	1	54.08 ns	76.67 ns	48.02 ns	0.2 ns	349.36 ns	2.2 ns	5.7-05 **	5-03 ns
Provenance x seasonal variations	5	29.89 ns	52.22 ns	32.83 ns	0.2 ns	181.4 ns	0.91 *	5.9-06 ns	7-02 ns
Tree / provenance	12	201.84 **	174.85 **	224.95 **	5.9 **	129.41 ns	1.2 ns	1.9-05 **	1.4-01ns
Seasonal variations x tree / provenance	12	19.54 ns	19.81 ns	19.91 ns	1.01**	82.78 **	0.66 **	1.2-05 ns	8.1-02 ns
Error	36	10.6	12.81	10.68	0.35	15.77	0.16	6.6-06	1.6-34

DL: degree of freedom, ns: not significant, *: significant at 5%; **: significant at 1%.

Table 7: Percentage of kernels (% K), of hull (% H), of pulp (% P), almond (A%) / fruit dry weight; the oil content / almonds weight (OCA) and oil content / fruit dry weight (OCF) observed during the 4th and the 5th seasons

Provenance		Tree	% K / fruit dry weight		% H / fruit dry weight		% P / fruit dry weight		% A/ fruit dry weight		OCF		OCA	
			4th season	5th season	4th season	5th season	4th season	5th season	4th season	5th season	4th season	5th season	4th season	5th season
AM	I	1	74.9 a	66.3 cd	68.8 ab	60 bc	25.2 gh	34.4 de	6 f	6.2 defg	2.7 cde	1.9 fgh	44.8 bc	29.8 de
		2	**51.9** j	59 efg	**44.6** e	50.4 f	**48.2** a	41 bc	7.3 bcdef	8.7 b	2.9 cde	2.4 cdef	39.6 cd	28.3 de
		3	75.3 ab	**72.8** a	68.2 ab	64 ab	24.7 gh	**27.2** g	7.1 bcdef	5.4 gh	3.2 bcd	**1.1** h	55.2 bc	**21.3** e
	II	4	**82.5** a	66.1 cd	**75.7** a	59.2 bcd	**17.6** h	33.9 de	6.8 cdef	6.7 de	2.6 cde	2.3 efg	38 de	33.7 cd
		5	51.9 j	51 h	45.5 e	44.8 gh	39.8 abcdef	49 a	6.4 ef	6.2 defg	2.4 de	3 bcde	37 de	48.2 ab
		6	67.3 bcde	62.9 def	59.1 cd	54.4 def	32.7 efghi	37.1 cd	8.2 abc	8.5 b	4 ab	3.6 b	49.3 ab	42.2 bc
	III	7	64.9 defgh	63.4 cde	57.7 cd	56.4 cde	35.1 bcdefg	36.6 cde	7.2 bcdef	7 cd	2.3 e	3.4b	**32.5** e	48.7 ab
		8	56.5 hij	56.1 g	50.5 de	49.8 fg	43.5 abc	43.9 b	**6** f	6.3 defg	**2.2** e	3.2 bcd	37.2 de	51.8 ab
		9	64 defghi	59.6 efg	56.2 cd	51.5 ef	36 bcdefg	40.4 bc	7.9 abcde	8.1 b	4.2 a	3.4 b	53.7 a	41.7 bc
	IV	10	65.3 defg	67.8 bc	58.8 cd	61.1 abc	34.8 cdefg	32.3 ef	6.5 ef	6.7 def	2.4 de	2.8 bcde	37.5 de	42.5 bc
		11	71.3 bcd	70.8 ab	64.7 bc	63.9 ab	28.8 gh	29.2 fg	6.6 def	6.9 de	3.3 bc	2.9 bcde	50.5 ab	41.9 bc
		12	66.4 cdef	65.4 cd	58.1 cd	59.4 bcd	33.6 defgh	34.6 de	8.4 ab	6 efgh	4 ab	1.6 gh	47.6 b	25.8 de
AR	I	13	68.2 bcde	71.4 ab	62.2 bc	**65.3** a	31.9 fgh	28.6 fg	6 f	6.2 defgh	3 cde	3.3 bc	49.6 ab	**53.4** a
		14	60.5 efghi	62.8 def	52.5 cd	54.8 def	39.5 abcdef	37.2 cd	8 abcd	8 bc	**4.3** a	3.5b	**54.3** a	43.4 abc
		15	58 fghij	58.9 efg	51.7 de	53.1 ef	42 abcde	41.1 bc	6.4 f	5.8 fgh	2.4 e	1.9 fgh	36.7 de	33.5 cd
AB	I	16	62.8 defghi	58.6 fg	56.6 cd	53 ef	37.2 bcdefg	38.3 cd	6.3 f	**5.1** h	3 cde	2.4 defg	46.6 b	46.5 ab
		17	57.7 ghij	59.7 efg	50.9 de	53.4 ef	42.4 abcd	40.3 bc	6.8 cdef	6.7 def	2.7 cde	1.9 fgh	39 d	28 de
		18	55.7 ij	**50.9** h	46.4 e	**40.7** h	44.4 ab	**49.2** a	**9.3** a	**10.1** a	4.2 a	**4.5** a	45.4 bc	44.2 ab
Average			64.2	62.4	57.1	55.3	35.4	37.5	7.1	6.9	**3.1**	**2.7**	44.1	39.2
Minimun			51.9	50.9	44.6	40.7	17.6	27.2	6	5.1	2.2	1.1	32.5	21.3
Maximum			82.5	72.8	75.7	65.3	48.2	49.2	9.3	10.1	4.3	4.5	54.3	53.4

Values followed by different letters are significantly different (LSD = 5%).

Influence of genotype

Genotype (tree / provenance) was highly significant for % kernel, % pulp, % hull and % almond, which shows differences between trees in each provenance (group) (Table 6). Tree x environment interaction (seasonal variation x tree / provenance) was highly significant for % almonds, oil content / almonds weight and oil content / fruit dry weight, which emphasizes the individual response of each tree in each site and each season. Average percentage of hull was more than 50% of fruit dry weight (Table 7). Average percentage of pulp, kernel varied respectively from 35.4% and 37.5%, 62.4% and 64.2%. Percentage of hull, almond varied from 55.3% to 57.1% and 7.1% to 6.9%. Almonds oil content varied from 39.2% to 44.1%, but oil content represented 2.7% to 3.1% related to fruit dry weight (Table 8).

Table 8 : Argan oil yield estimated for each tree from six provenance

Provenance		Tree	Yield of almonds (kg)			Oil yield (kg)		
			4	5	Average	4	5	Average
AM	I	1	1.0	0.5	0.8	0.4	0.2	0.3
		2	2.3	0.6	1.4	0.9	0.2	0.5
		3	1.5	0.1	0.8	0.7	0.0	0.4
Average			**1.6**	0.4	1	0.7	0.1	0.4
	II	4	2.2	1.8	2.0	0.8	0.6	0.7
		5	1.1	0.1	0.6	0.4	0.1	0.2
		6	**4.3**	2.5	**3.4**	**2.1**	**1.0**	**1.6**
Average			2.5	1.5	2	1.1	0.6	0.8
	III	7	0.7	0.8	0.7	0.2	0.4	0.3
		8	1.0	0.8	0.9	0.4	0.4	0.4
		9	2.6	0.7	1.6	1.4	0.3	0.8
Average			1.4	0.8	1.1	**0.7**	**0.4**	0.5
	IV	10	0.9	0.4	0.6	0.3	0.1	0.2
		11	1.9	0.7	1.3	1.0	0.3	0.6
		12	0.8	1.5	1.1	0.4	0.4	0.4
Average			1.2	0.9	1	0.6	0.3	0.4
AR	I	13	1.0	0.4	0.7	0.5	0.2	0.4
		14	**4.7**	1.4	3.0	**2.6**	0.6	1.6
		15	2.6	0.5	1.6	1.0	0.2	0.6
Average			**2.8**	0.8	1.8	**1.4**	0.3	0.9
AB	I	16	0.2	0.4	0.3	0.1	0.2	0.1
		17	0.3	0.5	0.4	0.1	0.1	0.1
		18	0.2	0.5	0.4	0.1	0.2	0.2
Average			0.2	0.5	0.3	0.1	0.2	0.1
Average			**1.6**	0.8	1.2	**0.7**	0.3	0.5

Index qualitative of argan oil

Refractive index

Seasonal variations, provenance and genotype (tree / provenance) were highly significant for the refractive index. Seasonal variations x provenance (environment effect) and seasonal variations x tree / provenance interactions were not significant (Table 6). Means were ranged between 1.454 to 1.465 during the 4th season and from 1.455 to 1.466 in the 5th season (Table 9).

Free fatty Acids

Seasonal variations, provenance and tree / provenance and their interactions have no significant effect on the percentage of free fatty acids (Table 6). The percentage of free fatty acids varies between 1.1 and 0.4% with an average about 0.7% (Table 9).

Table 9 : The free fatty acids (FFA) and the refractive index (RI) for the 4th and 5th seasons

Provenance		Tree	FFA		RI	
			4th season	5th season	4th season	5th season
AM	I	1	0.7	0.7	1.465 abc	1.465 a
		2	1.1	1.1	1.466 ab	1.465 a
		3	0.4	0.4	1.464 abcd	1.464 ab
	II	4	0.7	0.7	1.466 a	1.462 abcd
		5	0.7	1.1	1.464 abcd	1.463 ab
		6	1.1	0.4	1.46 def	1.456 de
	III	7	0.7	0.7	1.462 abcde	1.459 abcde
		8	0.4	0.7	1.459 g	1.455 e
		9	0.7	0.4	1.457 cdef	1.458 bcde
	IV	10	1.1	0.7	1.463 abcd	1.463 cde
		11	0.7	0.7	1.455 abcde	1.456 de
		12	0.7	0.4	1.46 bcdef	1.463 ab
AR	I	13	0.7	1.1	1.463 abcdef	1.462 abc
		14	0.4	0.7	1.463 cdef	1.46 abcd
		15	0.7	0.7	1.461 abcd	1.463 ab
AB	I	16	0.4	0.4	1.461 abcd	1.462 ab
		17	0.4	0.4	1.461 abcd	1.459 bcde
		18	0.4	0.4	1.464 abcdef	1.454 e
Average			0.7	0.7	1.5	1.5
Minimum			0.4	0.4	1.455	1.454
Maximum			1.1	1.1	1.467	1.465

Values followed by different letters are significantly different (LSD=5%).

DISCUSSION

The regression equation revealed that average weight of fruits harvested in the two frames, placed under each tree was highly correlated to total fruit production of trees. The average total production per tree is about 4.9 kg, it was ranged between a maximum of 11.1 kg and a minimum of 1.6 kg. The yield corresponding to the total fruit production of trees was highly correlated to the estimated yield by the sampling method. The maximum yield estimated was about 21.9 kg, the minimum was about 4.7 kg.

Estimated yield by this sampling method was similar to the results reported by Nerd et al. (1993) in an orchard irrigated trees (0.5 kg and 24.1 kg); and by Bani-Aameur et al. (1998) for ten trees in the field observed in Ait Melloul site (1.5 to 22.4 kg / season / tree). Since the designation of the argan forest as a Biosphere Reserve by UNESCO in 1998, recent attempts to sustainably develop region of argan by the implantation of several argan oil-producing woman cooperatives where high quality argan oil is now prepared[19]. Thus, to cope with the variability of argan fruit yields observed in the field, the use of this statistical method will allow to woman cooperatives to define fruit yield and therefore predict yield of argan oil. Also this sampling method would be useful for other purposes of scientific research on fruit yield and its components.

In a given season, our results showed a significant reducing of trees bearing fruit and yield component i.e. number of fruits (469.5 on average), fruit total weight (PT = 1.1 kg), and almonds weight (PA = 0.1 kg) and other components in Ait Baha, the driest site, during the first and the third season. Variability in frequencies of trees bearing fruit in the three stations between 93.3% in season of high production and 23.3 % in season of low productivity shows the significant effect of environmental factors on fruit productivity in argan in the wild state. In argan tree, fruit production extends over a long period from 9 to 16 months depending on the trees and fruits can be found in different ripening phases from April to September[11,14,34]. Variable frequencies and yield component can be explained by the very marked effect of seasonal variations in temperature and rain fall prevailing especially during the flowering period as has been reported in previous studies[12,11,13]. In case of drought during the flowering period, most trees in the next season do not produce fruits. But, if the flowering season was humid, fruiting in the following season will be higher. Thus, rainfalls during the first season especially between November and February, which corresponds to the period of growth, branching and formation of leaves and flowers in argan tree[13] were only 29 mm in Ait Melloul, 26 mm in Argana and 25 mm in Ait Baha. In addition, low rainfall between February and March in the 3rd season (2 mm in Ait Melloul, 8 mm in Argana and 22 mm in Ait Baha) were expressed by a small fruiting in the 4th season especially in Argana and Ait Baha sites. These results complement the finding reported Benlahbil and Bani-Aameur (1998) that late rains followed by a warm spring was unfavorable to fruit set. Rainfalls received in spring at the time of blooming and in autumn during fruit growth promote good fruiting. So we find the presence of three categories of fruiting trees. Trees that produced fruit in one season only, trees that can produce fruits in two, three or four seasons. Other genotypes were unable to produce fruits during the five seasons. The presence of about 10 % of fruiting trees in four seasons and 30%, 36% of trees bearing fruit respectively in three and two seasons in Ait Baha, shows the potential of genetic diversity in this endemic tree to south west Morocco as is reported for others morphological characters[18,13,27]. Therefore, Ait Baha, which creates the contrast, would consider as an environment for selection of resistant genotypes to seasonal variations in temperatures and rain falls for fruit productivity. These findings are in conformity with the findings of Sultan (2000) and Mückschel and Otte (2003) that argan tree shows a high adaptive plasticity with respect to his living environment as has been noticed in other plant species.

In other plants, many factors may simultaneously impose pressure on plants. Thus, optimal seed size, seed number or fruit production can also vary within plant species or populations as a result of many factors which modify fruit growth at any stage of development, mainly environmental conditions[35,36]. Drought, low temperatures, or soils poor in nutrients should be associated with reduced fruit crop volume or seed size[37,38]. Responses of trees to seasonal variations were highly heterogeneous, since the effect of genotype x environment interaction (tree x season x locality) were remarkable for fruit yield. Some genotypes (12, 17 and 24) from Ait Melloul, (2, 13, 26 and 29) from Argana were able to produce more fruits (10362.6 and 29298.2) and almonds (2 kg and 6.2 kg) during the 1st and 3rd seasons of high productivity. In addition, these genotypes can produce fruits even in season of low productivity (4th), since yield can reach 29.2 kg (13001 fruits) for fruits and 2.5 kg for almonds. Adaptation to climate change is imperative for arid environments; it should be the central element while developing planning strategies in argan ecosystems. Hence, domestication of argan can be done by giving emphasis on the selection and adaptation of genotypes that can withstand adverse weather conditions, as was the case of orchard crops in the Negev desert in Israel[16]. Those genotypes will be used as germoplasm for domestication of this species as a fruit tree for oil production. Therefore, to cope with water scarcity in flowering and fruit ripening seasons in argan ecosystems distributed in arid and semi-arid areas, it is necessary to develop an irrigation system in orchards coupled with a choice of “plus” genotypes, as was the case of other fruit species to ensure high fruit yields by enhancing fruit components and thus influence on the marketable yield for women cooperatives where the prised oil is extracted.

Locality and seasonal variations were not significant for % kernel, % pulp, % hull, % almonds, oil content / almonds weight and oil content / fruit dry weight, but environment effect was significant for oil content / fruit dry weight. This result is not consistent with the findings by Zunzunegui et al. (2010). These authors reported significant differences found among sites indicate that all the variables (fruit production, fruit mass, kernel mass, endocarp mass, and number of kernels per seed) were affected by the prevalent environmental and management conditions. This indicates that when conditions are unfavorable, either by drought or by herbivory, argan significantly reduces both fruit production and fruit mass. Genotype (tree / provenance) and tree x environment interaction influence significantly % kernel, % pulp, % hull and % almond, oil content / almonds weight and oil content / fruit dry weight. The interval of almonds oil content in our results (20.8 % - 55.2 %) includes values reported by other authors, despite differences in the chemical extraction method and origin of fruits. It was 50 % of kernel weight[26,25,16]. It varied from 49 % to 66 % of fresh weight of almonds from Argana, and between 55% and 72% of fresh weight of almonds from Goulemime[23]. Estimated annual yield of argan oil varies from 0.1 kg / tree to 2.6 kg / tree in the two seasons. Similar result was reported by Nerd et al. [16] in Keturah Israel (0.6 kg / tree) and it is 50 % less in Ramat Negev.

Seasonal variations, provenance and genotype influence the index qualitative of argan oil by modifying only the refractive index but not the percentage of free fatty acids. Annual average of the refractive index was about 1.461, it is within the range of the refractive index of Moroccan oil (1.46-1.47) [40] and less than value (1.47) for oil from Israel[16]. The percentage of free fatty acids varied between 1.1 and 0.4%, the same value was reported by Chimi et al. [21] for fruit from Ouled Taima. In addition, Zunzung et al.[4] showed differences in kernel oil content among populations and between years, while fatty acid composition was similar in the four populations and without a significant response to climatic condition or human pressure**.** Similar results for acid index (0.7 to 2.1) as reported by Flour et al. (1984) for Moroccan oil but without mentioning the fruit origin as well as the Israeli oil (2 and 2.8) [40].

CONCLUSION

The main aim of the present study is to evaluate the effects genotype and environment on fruit and oil productivity. Responses of trees to seasonal variations were highly heterogeneous, since the effect of genotype x environment interaction (tree x season x locality) were remarkable for fruit yield and fruit components. Drought effect induced a net reduction in frequencies of trees bearing fruits, fruit yields and fruit components in the three geographical origins. Argan is a threatened species whose populations suffer regression area and density which will induce the genetic erosion. An important genetic variation exists between individuals within each site. Ait Baha, which creates the contrast, would be considered as an environment for selection of resistant genotypes to seasonal variations in temperatures and rain falls. Moreover, this result has practical implications for genetic management of resource for future domestication programs of argan as oil-producing tree which is still in the wild state. Argan tree is also contributing to the local economy, making it a potential candidate for domestication and a useful source of drought resistance and last defense against desertification.

Acknowledgements

We gratefully acknowledge anonymous reviewers and office journal which provided helpful comments that greatly improved the manuscript. We thank the Morocco-Germany Co-operative Project ‘Conservation Project and Development the argan forest’(PCDA-GTZ) and the project Pars-Agro 128 of the Morocan Ministery of Scientific Research for financial support.

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