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Agronomic features of introduced Argan tree in eastern of Morocco and optimization of their propagation

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Abstract: *Argania spinosa* or argan is an endemic plant of Morocco that belongs to sapotaceae family. This species has significant ecological and socioeconomical impact in Morocco and is mainly recognized by argan oil that is very known for its nutritional quality and health benefits. Our study aims to elaborate an agronomical and pomological characterization of introduced argan trees in Oujda, Morocco (about 200 trees, 10 years old) , select high-performance clone heads based on their productivity and stability criteria, by measuring various productivity parameters over a tree years study period (fresh fruit production, almonds production and oil production), and successfully propagate them asexually using apical grafting technique in controlled condition (phytotron) with the aim of stabilizing the high-performance clone. The obtained results indicated the existence of high diversity in terms of the various pomological parameters assessed. Parallelly, productivity and profitability parameters, the average production of fresh fruits, almonds and oil per tree and per year was 8.62 kg, 0.253 kg and 0.133 L, respectively. While, the maximal production was 34.4 kg/year for fresh fruits production, 1.07 kg/year/tree for almonds, and 0.575 liter/year/tree oil produced. Regarding the propagation of these clones, the results showed that the grafting success rate depended on the mother stock and the season, with 100% success rate. The results obtained show that the argan tree is an adaptive species, and the most suitable grafting method for the argan tree is apical split grafting during the autumn season.

Keyword: *Argania spinosa;* Introduction; Selection; Optimization; Eastern Morocco; Multiplication.
Abbreviation: K/F: kernel/fruit ratio; A/K**:** Almond/Kernel ratio; **A/F:** Almond/fruit ratio; **W/L:** with/length ratio; **G:** genotype, **PC1:** principal component 1, 2

Introduction

Argania spinosa also called argan tree is a wild forest species, belonging to sapotaceae and is considered endemic tree to Morocco (WFO 2022). This plant presents high ecological and socioeconomical impact (Azizi et al., 2021; Gharby et al. 2022). Furthermore, this endemic species is mainly concentrated in the south of the country, covering an area of 700,000 ha (Moukrim et al. 2018).
However, the present of relics witness to the ancient existence of the argan tree in northern Morocco, notably in the beni-znassen mountains where it covers an area of 700ha (Emberger 1924, 1925; Tazi et al. 2003; Faouzi et al. 2014; Réda and Benamar 2020).
Argan oil is considered as one of the main products of the argan tree, which is famous worldwide with its nutritional value and with numerous health benefits (Azizi et al. 2024). And the known health benefits of the plant is attributed to the oil richness with unsaturated fatty acids, tocopherols, and with phenolic compounds (Kamal et al. 2019).
The argan tree presents a great diversity in terms of production and pomological characteristics. Moreover, a great diversity between individuals in terms of productivity was noticed, which is a major criterion for selecting high-performance clones (Metougui 2017). Regarding argan production, fresh fruit production varies between 1.5 and 22.5 kg/ha, while almond production is in the order of 41 - 2318 g/tree which represents approximately 6.7 - 7.1% of the fresh fruit weight (Bani-Aameur 2001; Zunzunegui et al. 2010). Finally, according to (Hammou et al. 2018) oil production varied between 0 – 1866 mL/tree.
Regarding argan pomological parameters, several fruit shapes have been found, such as oval, spindle-shaped, rounded (Bani-Aameur 2001).
In order to stabilize the interesting characteristics of a selected clone, propagation by asexual means is the key to its success (Azizi et al. 2022b). Several methods have been used to date in argan production, either by grafting or cuttings, but propagation by grafting remains the most widely used, given its simplicity and high success rate (Bellefontaine et al. 2010). On the other hand, it has been shown that experimental conditions play a crucial role in grafting success, such as temperature, relative humidity and light intensity (Mokhtari 2002). In order to have an efficient

selection of genotypes with high performance, several criteria must be taken into consideration, such as fresh fruit production, kernels yield, total oil content, and finally the physicochemical characteristics of the oil (Azizi et al. 2022a). The main aim of this study is to perform the agronomic characteristics of introduced *Argania spinosa* in eastern Morocco such as fresh fruit production, almond production and tree production per tree, and study the existing relation between the different productivity criteria among the species in the objective of selecting to high performing clones, and the optimization of their propagation using apical grafting technique.

Results

Agronomical and pomological characteristics of introduced argan in Oujda city

Pomological variability

The results of the evaluation of the various pomological parameters of the 18 trees are represented in the **table 1**. According the obtained results, we noticed that the pomological characteristics of argan tree represent a range of diversified values. Concerning the fruits average it was noted a weight of 9.57g with a maximum value of 15.86g. The maximum length of the fruit is about 3.79 cm, while the average value is 3.09 cm. On the other hand, it was mentioned that the fruit width varies between 1.62 cm and 2.94 cm. while, cored weight oscillates between 1.27 g and 3.92 g with an average value of 2.36 g. Regarding the length varied between 1.72 cm and 2.47 cm with an average value of 2.1 cm. Regarding the width, the maximum and minimum values are around 1.72 cm and 1.12 cm respectively. However, the kernels weight varied between a maximum of 0.542 g and a minimum of 0.162 g. As for the dimensions, the maximum length recorded was 1.95 cm while the lowest value was around 1.45 cm. The width of the kernels was 1.06 cm on average, with a maximum value of 1.23 cm. Regarding the weight ratios, the stone represents on average 25.18% of the total fruit weight, while the kernels represent on average 3.04% of the total weight of the fruit with a maximum value of 4.66%.

Agronomic variability

For better agronomical variability evaluation, 18 subjects were followed regularly for 3 years. The fresh fruit production varied between 34.46 kg and 0.47 kg/tree, with an average value of 8.62 kg. Regarding kernels production, it varies between 1.07 kg and 0.01 kg/tree, with 0.253 kg/tree as mean value **(Table 2)**. Regarding oil content, that was obtained using chemical extraction, the maximum content recorded was 55.16%, while the lowest value was 47.6%, on average the oil content was 51.9%. Finally, regarding the oil production/tree, the maximum value recorded was 0.575 L/tree, while the lowest value was 0.007 L/tree, and an average oil production of 0.133 L/tree.

Selection of the best performing clone heads

To study the existing relation between the various studied parameters the principal component analysis (PCA) was adopted as well as to elucidate the characteristics of each genotype. From **Fig 1A** and **B**, it could be seen that the majority of the data is explained by the first two components (PC1 and PC2) with a contribution of 46.72% and 25.98% for PC1 and PC2, respectively. The first component was negatively correlated with fresh fruit production, oil production, almond production, oil content, and finally the rate of almonds per kernel while it was positively correlated with the percentage of kernels/fruit. Concerning the second component, it was positively correlated with the oil content, the percentage of almond per stone and negatively with the percentage of almond/fruit, and stone/fruit. It is also noted that the oil content was positively correlated with the percentage of kernels per stone, on the other hand, the fresh fruits production was positively correlated with the production of oil and kernel.

Concerning genotypes distribution, genotypes O2, O1, O6, O7, classified by order of proximity, were negatively aligned to the axis of the first component, which means that they are the most productive, especially in terms of fresh fruit (FFP), almond (AP) and oil production (OP). On the other hand, they were aligned in the middle of the axis of the second component, which means that they are characterized by an average oil content and kernel/kernel rate. On the other hand, genotypes O4, O5 and O8 were aligned in the middle of the too axis (first and second components) these genotypes are characterized with medium value regarding the fresh fruits and kernels production

Finally, genotypes O10, G-O11, O12, O13 and O18, were positively aligned to the axis of the first component, these genotypes are characterized by a low production of both fresh fruits and kernels. Also, they were positively aligned to the second component axis, which results in a low kernel/fruit ratio.

Regarding the selection process, the genotype represented by the first (O2) and second groups (O1, O6 and O7) were considered as the bests clones heads, regarding there Hight FFP, OC and AP. On the other hand, the genotypes O4, O5 and O6 where considered as promising clones, and were selected too, but as second-class clones, regarding their medium production in terms of fresh fruits, and almonds. These clones will be subject of a monitoring next year.

The first group (**Fig 2**) is represented by seven (7) genotypes named O5, O8, O10, O11, O12, O13 and O18 and are characterized with medium to High almond/kernels ratio and oil content. However, they are characterized by a low PFF, AP and OP excepted for genotypes O5, O8 that are characterized with a medium PFF, AP and OP. The second group was represented by six (6) genotypes (O4, O9, O14, O15, O16, O17) that are characterized with a medium Almond/fruit and kernels fruits radio, with a low PFF, AP and OP. While, genotypes O1, O6 and O7 were found to represent the third group, and are characterized with medium to Hight PFF, PA and PO and High oil content. Nevertheless, the fourth group was composed of one genotype named O2, that is characterized with High PFF, OP and AP.

Finally, the genotype O3 was found to be the only constituent of the sixth group, which is characterized with High almond/fruit and Kernels/fruit ratio, and low fresh fruit production, almond production and oil production.

Statistical correlation

The correlation between the different studied parameters is represented in **Fig 3** below. The results indicated the presence of a positive correlation between the different production parameters such as fresh fruits production, almond production and Oil production. However, it was found the presence of a negative correlation between almond/kernels ratio and Kernels/fruits ratio, indicating that if the percentage of the almond in the kernel is High, the percentage of the kernels in fruits will be low and the opposite is corrected.

Characteristics of selected clone heads

Pomological characteristics

Regarding fruits pomological characteristics from the selected plants, genotype O4 was characterized by the highest fruit, stone and kernel weight, with values of 15.86 g; 3.92 g and 0.542 g respectively. While, the lowest values were

Table 1. Variation of pomological characteristics of studied trees.

Parameters			Maximum	Minimum	Mean
Dimensions (cm)	Fruit	Length (L)	3.79	2.27	3.09
		Width (W)	2.94	1.62	2.09
		l/L	0.85	0.47	0.68
	Kernels	Length	2.47	1.72	2.1
		Width	1.72	1.12	1.39
		W/L	0.69	0.65	0.66
	Almonds	Longueur	1.95	1.42	1.611
		Width	1.23	0.79	1.06
		W/L	0.67	0.63	0.65
Weight (g)	Fruit (F)		15.86	5.9	9.57
	Kernels (K)		3.92	1.27	2.36
	Almonds (A)		0.542	0.162	0.29
Ratio (%)	K/F		47.18	14.8	25.18
	A/F		4.66	1.92	3.04
	A/K		18.37	8.96	12.63

Table 2. Variation of the production of the studied trees.

Parameters	Maximum	Minimum	Mean
Fresh fruits Production (Kg)	34.466	0.47	8.62
Almonds Production (Kg)	1.07	0.01	0.253
Oil Production/Tree (L)	0.575	0.007	0.133
Oil content (%)	55.16	47.6	51.9

Table 3. Pomological characteristics of selected clones.

Clones			O5	O7	O2	O1	O4	O8	O6
Weight (g)	Fruit		9.32 ± 2.10^{ab}	5.91 ± 0.99^{a}	8.59 ± 1.92^{a}	14.17 ± 2.26^{bc}	15.86 ± 2.49^{c}	10.1 ± 1.3^{ab}	13.83 ± 0.87^{bc}
	Kernel		2.17 ± 0.23^{ab}	1.56 ± 0.29^{a}	1.82 ± 0.55^{a}	3.11 ± 0.73^{ab}	3.92 ± 1.30^{b}	2.17 ± 0.24^{ab}	3.20 ± 0.26^{ab}
	Almond		0.269 ± 0.08^{a}	0.184 ± 0.05^{a}	0.266 ± 0.09^{a}	0.439 ± 0.17^{a}	0.542 ± 0.33^{a}	0.194 ± 0.03^{a}	0.365 ± 0.01^{a}
Dimensions	Fruit	L	2.59 ± 0.23^{a}	2.27 ± 0.09^{a}	3.79 ± 0.26^{c}	3.22 ± 0.133^{b}	3.382 ± 0.367^{bc}	3.43 ± 0.33^{bc}	3.17 ± 0.05^{b}
		W	2.06 ± 0.1^{ab}	1.94 ± 0.201^{a}	1.898 ± 0.108^{a}	2.34 ± 0.120^{c}	2.994 ± 0.113^{d}	2.082 ± 0.149^{abc}	2.27 ± 0.03^{bc}
		W/L	0.69	0.85	0.47	0.71	0.85	0.60	0.71
	Kernel	L	2.12 ± 0.14^{ab}	1.76 ± 0.11^{a}	$2.22\ 0.17^{ab}$	2.29 ± 0.21^{b}	2.46 ± 0.26^{b}	2.31 ± 0.19^{b}	2.24 ± 0.04^{ab}
		W	1.34 ± 0.13^{a}	$1.29\ 0.11^{a}$	1.25 ± 0.14^{a}	1.58 ± 0.14^{ab}	1.72 ± 0.18^{b}	1.40 ± 0.17^{ab}	1.51 ± 0.01^{ab}
		W/L	0.63	0.73	0.56	0.68	0.69	0.60	0.67
	Almond	L	1.81 ± 0.09^{ab}	$1.42\ 0.09^{a}$	1.72 ± 0.10^{ab}	1.76 ± 0.15^{ab}	1.95 ± 0.34^{b}	1.68 ± 0.17^{ab}	1.7 ± 0.01^{ab}
		W	1.15 ± 0.07^{c}	$0.79\ 0.08^{ab}$	0.89 ± 0.06^{abc}	1.01 ± 0.14^{abc}	1.12 ± 0.13^{c}	0.715 ± 0.20^{a}	1.09 ± 0.01^{bc}
		W/L	0.63	0.55	0.51	0.57	0.57	0.42	0.67

Values followed by different letters are significantly different ($P < 0.05$). Values with the same letters indicate no significant difference ($P > 0.05$).

recorded by plant O7 with fresh fruit, stone and kernel weight of 5.91 g; 1.56 g and 0.184 g respectively (**Table 3**). Regarding fruit length, genotype O2 recorded the highest value which is 3.79 cm, and the lowest value of 2.27 cm was recorded in genotype O7. On the other hand, the longest kernels and Almond were recorded by the O4 genotype with values of 2.46 cm and 1.95 cm, respectively.

Productivity and profitability

The clones were selected on the basis of their high productivity then, were classified into two categories regarding vigor. Genotypes O5 and O7 belong to the low vigor class, while genotypes O1. O2 and O8 are characterized by high vigor **(Table 4)**. This classification makes it possible to adapt the number of plants planted per hectare. which will vary according to the vigor of the tree. Genotypes with low vigor can be planted at a higher density than those with high vigor.

The O4 genotype was selected for its interesting ornamental characteristics, since it is characterized by a weeping aspect, a vegetative growth during the whole year and the absence of thorns.

Regarding the productivity and profitability parameters, the highest values were recorded in the O2 genotype, with a maximum fresh fruit production of 34.4 kg and an almond and oil production of 1.455 kg and 0.793 liter respectively.

The lowest values were recorded by the genotype O8. with a yield in kernels that is 0.316 kg. in oil of 0.166 liter. in spite of its production in fresh fruits that is average (13kg). In fact it is due to the low weight of the kernel compared to the weight of the fruit where the kernel represents only 2.29 % of the total weight of the fruit. This can be explained by a problem of self-pollination since this plant is planted in an isolated place in a private property.

On the other hand, the O4 genotype was characterized by a low oil production which was about 47%. The oil production per hectare was estimated for a plantation density of 400 plants/ha (6 x 4). It is the highest in the O2 genotype, with an average value of 208 L and a maximum value of 317 L. Concerning the alternation rate, which corresponds to the difference observed between the maximum and minimum values of fruit production per plant during the three years of monitoring, the highest alternation rate was noted in the O5 plant with a value of 68.52%, while the lowest alternation rate was recorded by the O2 genotype with a value of 5.57%.

Study of the effect of graft harvesting season and genotype on grafting success (4 weeks-old rootstock)

Bud burst rate

The grafting operation took place in two different seasons (autumn and spring). These two seasons are characterized by

Table 4. Productivity and profitability characteristics of selected clones.

Viguor		**Weak**		**High**				
Clones		**O5**	**O7**	**O2**	**O1**	**O4**	**O8**	**O6**
Almond/fruit %	Medium	2.89^{abc}	3.11^{abc}	3.103^{abc}	3.1^{bc}	3.41^{c}	1.92^{a}	2.63^{ab}
	Optimum	3.77	4.02	3.45	4.3	**5.55**	2.29	2.86
Oil %	Medium	53.7^{c}	53.85^{c}	53.53^{c}	55.16^{d}	47.6^{a}	51.86^{b}	52.23^{bc}
	Optimum	54.37	54.4	54.8	56.26	48.1	52.81	53.78
Production (Fresh fruit)	Medium	8.5^{ab}	9.422^{ab}	31.33^{d}	13.26^{bc}	4.7^{a}	12.3^{abc}	15.29^{c}
	Optimum	14.334	13.49	34.4	18.062	10.27	13.8	22
Production (almond/tree)	Medium	0.24^{a}	0.293^{a}	0.972^{a}	0.411^{b}	0.161^{a}	0.236^{a}	0.402^{a}
	Optimum	0.54	0.54	1.455	0.776	0.564	0.316	0.629
Production oil/tree (L)	Medium	0.132^{a}	0.157^{a}	0.52^{b}	0.226^{a}	0.076^{a}	0.122^{a}	0.209^{a}
	Optimum	0.293	0.54	0.793	0.436	0.271	0.166	0.333
Production/Ha (L)*	Medium	52.8^{a}	63.11^{a}	208^{b}	90.73^{a}	30.66^{a}	49^{a}	83.6^{a}
	Optimum	117.52	118.47	317	174.78	108.7	66.75	133.2
Alternance (%)		68.52	43.23	5.57	29.64	9.56	12.15	26.37

(Average values: average of the values recorded during 3 years. Optimal values: maximum value recorded during the 3 years of study). Values followed by different letters are significantly different ($P < 0.05$). Values with the same letters indicate no significant difference ($P > 0.05$).

an abundant production of young branches. During the autumn season and after the defoliation of the tree during the summer, a growth resumption is noticed. Similarly for the spring season, the production of young shoots is abundant however these last ones are characterized by the presence of floral buttons. The results pictured in **Fig 4** shows that the success rate varies between 83% and 100% depending on the genotype. The highest values were recorded by the G5 genotype. While, the lowest rate is recorded by the G3 genotype. Parallelly, the losses are all related to graft rot. Moreover, the values were found to vary between 0 and 16% where the highest values are recorded by genotype G3. Finally, genotype G5 showed no losses.

Regarding the grafting operation by grafts taken during the spring season. the results report that the grafting success rate varied between 66.6% and 100%. The highest rate was recorded by the G5 genotype, while the lowest value was that of the G3 genotype. In comparison with the results of fall season, the two genotypes G6 and G3 showed a drop-in success rate of about 16% and 17% respectively. On the other hand, an increase in the failure rate due to graft desiccation was observed, as well as the appearance of grafting failures caused by fungal attacks, particularly for the G6 and G3 genotypes **(Fig 5).**

The performed statistical analysis indicated that the season effect was statistically significant ($P<0.05$) on bud break rate, while no statistical significance was noted on desiccation and rot rate ($P>0.05$). On the other hand, the effect of genotype was statistically significant on the rate of bud burst and desiccation ($P<0.05$) and without effect on the rate of rot. Finally, the existing interaction between season and genotype has no statistical significance on the different measured parameters.

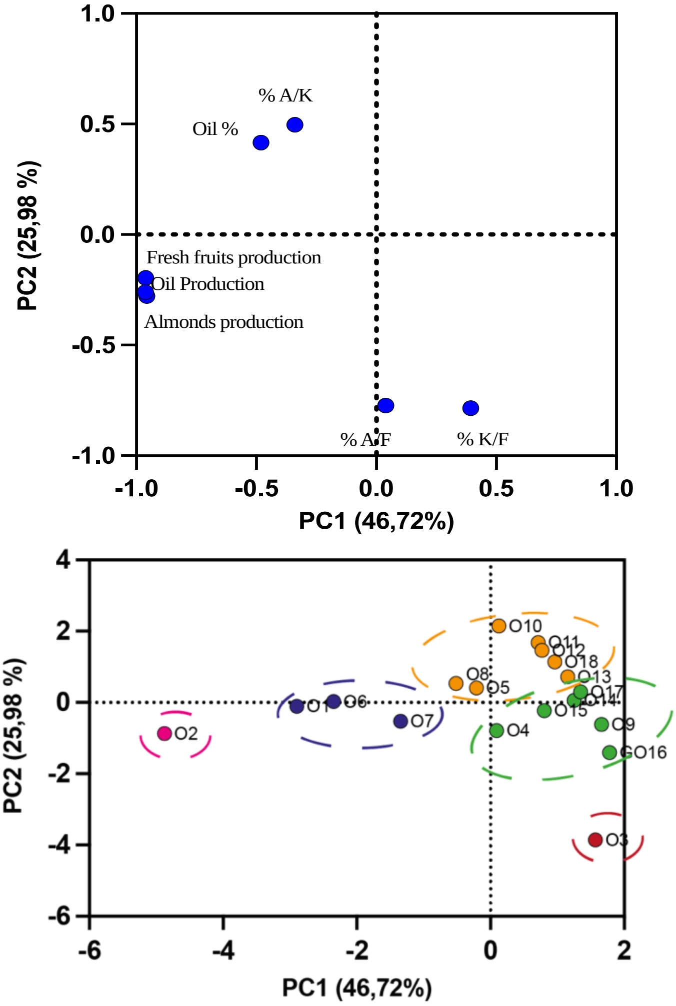

Fig 1. Principal component analysis. A: variables distribution, B: genotypes distribution (the colors coresponds to the clusters produced by HCA).

Discussion

Argan tree is characterized by a significant diversity especially in terms of pomological characteristics of its fruits, almonds and kernels which are characterized by dimensions and shapes that are of high variability. These findings were reported earlier in the study assessed by (Metougui 2017), who evaluated the extent of fruit variability of some genotypes of Argan tree in Admin.

Several authors have measured the fruit production of argan trees in terms of density per square meter, which is suitable for specific situations such as tree vigor, population extent, and constraints related to measurement methods. However, Hammou et *al.* (2018) measured the total production per tree which was similar to our case, we opted to measure the total production per tree by harvesting the entire yield of the tree for several reasons, such as increased precision, the Measuring of the production of the entire tree provides an accurate assessment of yield, without approximations caused by variations in fruit density across different parts of the tree. This approach leads to a better estimation of total productivity on the other hand, Fruit production can vary

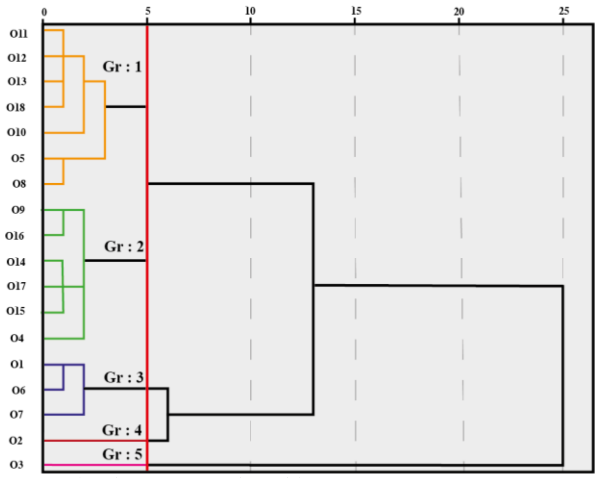

Fig 2. dendrogram produced by HCA.

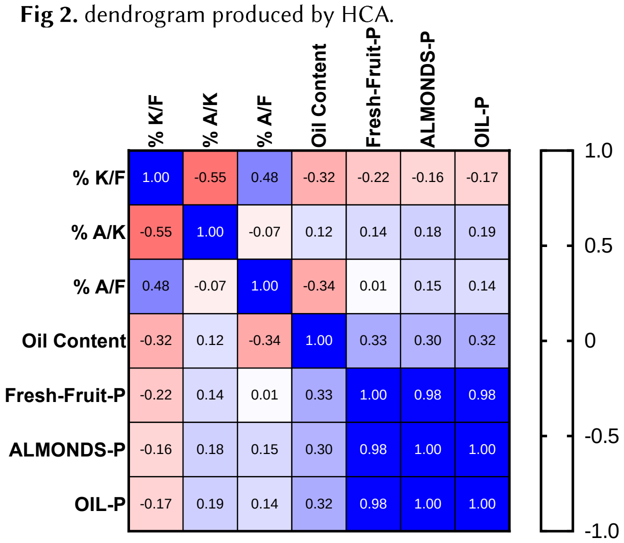

Fig 3. Correlation heatmaps between the studied parameters.

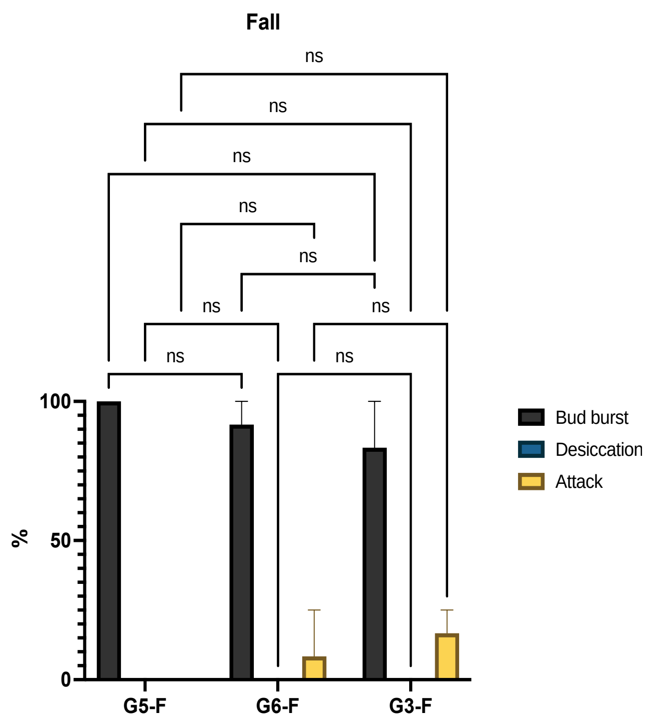

Fig 4. Budding rate 1 month after grafting operation (fall season).

significantly from one part of the tree to another (e.g., due to sun exposure, ventilation, etc.). By measuring the whole tree, errors associated with local variability in production are minimized. However, A complete measurement helps to better manage resources like water and nutrients, as it provides an understanding of the tree's overall response to interventions, rather than relying on estimates that might be skewed by spatial variability. Finally for scientific research, measuring the entire tree's production is essential for accurate comparisons between different varieties or cultivation methods. This approach ensures more robust and representative data (Sarle 1932).

The production of fresh fruits varies between 0.47 kg/tree and 33.46 kg/tree. These results are in accordance with those found by Bani-Aameur (2001), who indicated that the production varies between 1.5 kg and 22.5 kg of fruits per tree. On the other hand, Nouaïm et al. (2007)) indicated that the production of fresh fruits of the Argan tree varies between 10 kg for the trees with weak vigor and vary from 30 to 65 kg for the trees with average to high vigor.

In fact, the different trees reported in the different studies found in the literature are old trees and are in the natural range of the argan tree, which was different from our study where the subjects evaluated are about ten years old which explains the difference between the maximum production observed in our study and that reported by other authors.

Other performed studies have evaluated the production by a method based on the density of fruits/m^2, notably Zunzunegui et al. (2010) who have indicated that the number of fruits varies between 40 and 250 fruits/m^3. Meanwhile, Metougui et al. (2017a) found that it varies between 54.79 and 90.15 fruits/m^2 depending on the year and genotype.

In the present study, the oil content ranged from 47.6 to 55.16%. These results are in agreement with those found by Metougui (2017) who reported that the oil content in the selected performing genotypes in Admin forest ranged from 47.4% to 57.9%. On the other hand, Hammou et al. (2018) reported that the oil content percentage is 47.67% for old trees and 46.67% for young trees. While the oil/fruit yield is 3.67% and 3.05% for old and young trees respectively.

Additionally, the selected subjects showed an oil production/tree that ranged between 176 mL and 793 mL and an oil production/ha that ranged between 66 L and 317 L. These results are comparable to the results obtained by Metougui et al. (2017) that have focused on the selection of successful subjects in the Admin forest. Indeed, they have found that the oil production/tree of the selected subjects varied between 410 mL and 1027 mL, and the estimated production per hectare was from 164 L to 726 L. In addition, . Zunzunegui et al. (2010) have indicated that the oil production/ha in the Argan tree in its natural domain is between 0.9 and 35.5 L depending on the areas and regions and that the trees located in coastal areas are the most productive.

The results showed that grafting success of the argan tree depends on several factors such as the season of grafts harvest, the mother plant. Thus, it was also shown that the effect of these factors is controlled by the genotype.

Concerning the effect of the season on the success of grafting, a slightly difference was observed in the success rate for genotypes G2 and G3, while the genotype G1 gave the same values without statistically significant difference between the two seasons. These results are in agreement with those obtained by Bellefontaine (2010) who showed that the best grafting success rates were obtained in November and March (Autumn and Spring) and that the autumn season is the most favorable for grafting. since the grafts taken during the period between March and July are characterized by the presence of flower buds that can affect the success rate of grafting (Bellefontaine et al. 2011).

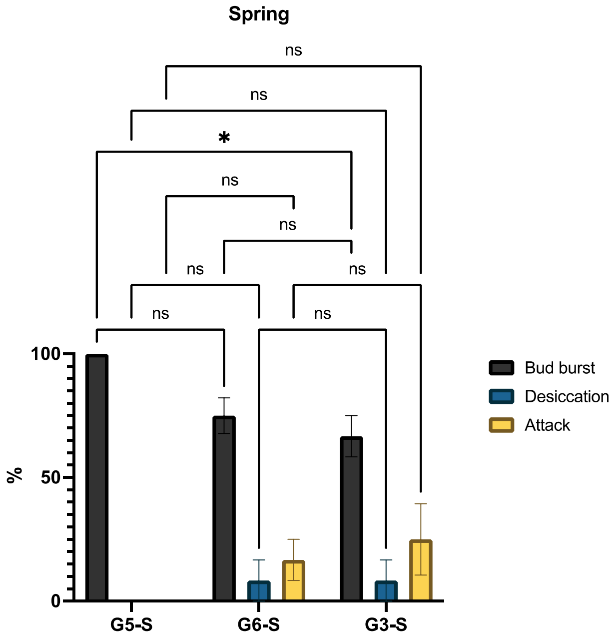

Fig 5. Budding rate 1 month after grafting operation (Spring season).

On the other hand, these results are in agreement with those of Bellefontaine (2010) who showed that the grafting in apical cleft in argan tree requires a high relative humidity higher than 85% and an average temperature between 20 and 25 °C and outside these limits. the failure rate will be high. On the other hand, Hartmann and Dale E Kester (2014) mentioned that the formation of the grafting bridge (tissue contact) and the union of the vascular vessels requires a temperature between 15 and 32°C. a relative humidity of 95 to 100% and beyond these limits. callus production is delayed. Finally, the study by Mokhtari et al. (2011) showed that growing conditions play an important role in grafting success. Indeed. the success rate of grafting in a greenhouse is 0% regardless of the type of rootstock. In addition, grafting in a growth chamber with controlled climatic conditions resulted in success rates that range from 30% to 87%.
On the other hand, the incompatibility between the graft and the rootstock may also be among the causes of the low success rate noticed in some genotypes. This was shown by Metougui et al.(2017) who mentioned that the low success rate in some genotypes may be explained by their incompatibility with the rootstocks used.

Materials and Methods

Plant materials

On the basis of several argan genotypes (218) introduced in Oujda city (Azizi et al. 2022a), a preliminary selection resulted in the selection of 18 mature and productive genotypes. These different selected trees were chosen to be part of a pomological and agronomic characterization aimed at selecting the best performing genotypes. For this purpose, the genotypes concerned by the study were all adults, aged more than 10 years old. These trees were planted in 2010 at the different green spaces of the Faculty of Sciences, Mohammed the first university and in other places of Oujda city. The preliminary selection was based on the spacing of the adult plants that are not productive. On the other hand, the sanitary state and the vigor were also taken into consideration.
The 18 selected genotypes were named from O1 to O18 and their geographical location is pictured in F**ig 6**.

Climatic characteristics

Oujda is a city which is located in eastern Morocco, which is characterized by a dry Mediterranean climate and a semi-arid bioclimate with cool winters and by dry and hot summer periods with low annual precipitation (**Table 5**).

Determination of pomological paramters

Several pomological parameters were measured to determine the existing variability between the different genotypes such as length, width, weight of fresh fruits, kernels and almond. As well as the different relationships between these measured parameters such as weight ratios (kernel/stone, kernel/fruit and stone/fruit) and size ratios of fruits, stones and kernels.

Determination of production

The produced fruits by each tree were measured by weighing the whole plant production by harvesting the ripe fruits of each tree for a period of 3 years. The obtained results are expressed in kg/tree. The maximum production is considered to be the highest value recorded during the 3 years of monitoring, while the average production is the average of the 3 years.
The alternance rate that represents production stability over a period of three years was measured according to the formula (Hammou et al. 2018):

$$A\% = \frac{PFFmax - PFFmin}{PFF\ max} * 100$$

A%: Alternance rate
PFFmax: maximal Fresh fruits production (over 3 years)
PFFmin: minimal fresh fruits production (over 3 years)

Determination of oil content

Fifty grams of dried almonds were turned into fine powder and then extracted in a soxhlet apparatus using n-hexane (250 mL) for about 3h until total exhaustion of the plant material. The rotary evaporator was used to eliminate the residual solvent in order to obtain crude extract. The obtained fixed oil was put in dark glass bottles and kept in a temperature of -20°C for further use (Azizi et al. 2022a).

Optimization of selected argan trees propagation

Grafting trial

The grafting trial aims to study the effect of two factors, the season of graft harvesting (fall-harvested graft, spring-harvested graft) and the effect of selected genotypes (G3, G4, and G5).

Culture conditions

The plants were grafted in a growth chamber with a temperature of 18°C. Then, the plants were placed in plastic boxes filled with water to a certain level in order to minimize the water supply and put in a culture chamber with a temperature of 18°C ± 2°C, a humidity considered as saturating and a light intensity lower than 500 lux for 3.5 days to allow the first contact of the tissues. The light intensity was gradually increased to 1000 lux. The first phase of acclimatization took place in a phytotronic enclosure with a luminosity of 1500 lux and a temperature fluctuating between 22°C and 27°C and a relative humidity between 85% and 94%. While, the second phase of acclimatization consisted in putting the plants in a shaded tunnel under a glass greenhouse with a luminosity of 2500 lux and a temperature varying according to the external conditions.

Table 5. Climatic characteristics of the studied area (Abatzoglou et al., 2018).

Years	TMAX (°C)	TMIN (°C)	TAVE (°C)	PPT (mm)	ALT (m)	Bioclimate
2020	23.9	11.2	17.6	230.6	618	Semi-arid (Cool winter)
2021	23.8	11.1	17.4	198		
2022	24.6	11.7	18.1	212.5		

Fig 6. Geographical locations of the studied genotypes at Mohammed the first University Oujda Morocco.

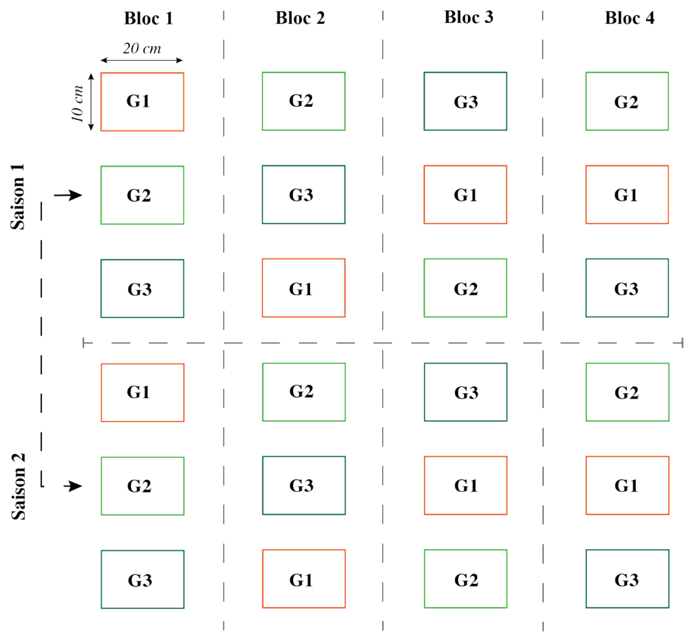

Fig 7. Experimental design of grafting trial.

Measured parameters

The measured parameters for the first and the second assay were, bud break rate, attack rate and success rate after acclimation.

Effect of season and genotype on grafting success (PG 4 weeks)

A complete randomized block design with a total number of 96 grafted plants were used (3 genotypes x 2 seasons x 4 plants per combination x 4 blocks) (**Fig 7**).

Statistical analysis

The collected results were subject to statistical descriptive analysis and variance analysis (ANOVA), using SPSS Windows version 23 and the comparison between the different means was done using Duncan test with a probability threshold of 5%. The different parameters of productivity and rentability were subject to principal component analysis PCA and hierarchical classification HCA.

Conclusion

According to the results obtained, the introduced argan tree presents an important variability in terms of pomological characteristics, production and profitability. The production in fresh fruits, in oil/tree and per hectare was very close to the results obtained by other authors concerning the southern argan tree. These results indicated that the argan tree is a species characterized by a plasticity towards the climatic conditions different from its natural biotope.

Additionally, the selection of successful subjects from an introduced population is an important step in the domestication of the argan tree, since it is a selection based on subjects adapted to the climatic conditions of the city of Oujda and therefore the ease of their integration into the tree procession.

The results showed that the grafting in the argan tree depends on several factors, such as the effect of the mother plant as well as the age of the rootstock. Indeed, the juvenility of the rootstocks plays an essential role in the success of the grafting which ensures a high speed of establishment of the vascular connections between PG and graft. due mainly to the turgidity of tissues allowing a better contact between graft and rootstock. The delay in the establishment of vascular connections can increase the risks of desiccation or rot. In addition. the use of the young graft carriers allowed to shorten the duration of breeding of the grafted seedlings in controlled conditions (one month) what allows to accelerate the procedure of production of plants of argan grafted in mass.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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