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Effect of edapho-climatic conditions on fruit productivity, yield and olive oil quality in olive orchards (*Olea europaea* L.): case of a semi-arid region

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Abstract

The objective of the present work is to evaluate the relationship between the edapho-climatic conditions of the cultivation environment and the variability of olive productivity, yield, and quality of olive oil in orchards of the Moroccan Picholine (PM) population variety (*Olea europaea* L.). This work was carried out on different agricultural territorial units (agroecosystems) of the Beni Mellal-Khenifra region with a semi-arid climate during four agricultural seasons (2016/2017 to 2019/2020). For this purpose, the relevant agronomic and agro-biochemical parameters were studied, namely the stage of maturity, fruit and olive oil yields and quality indices. The data treatments of the results were performed according to descriptive and affiliated statistics by analysis of variance (ANOVA). We have found significant correlations (according to Pearson's R) between agroecosystems, particularly for weight of crude olives produced per hectare and temperature (R= 0.803), olive yield and humidity (R= 0.654), olive oil yield and temperature (R= 0.837), olive oil richness and humidity (R= -0.622), as well as the qualitative characteristics of the extracted oils, through the levels of free acidity and peroxide value (R = 0.467). These results confirm that in the studied semi-arid environments, the properties of the biotope of the cultivated olive groves, combined with the interannual agroclimatic variability, effectively influence the productivity of the olive trees, the oil production and the chemical and organoleptic quality of the extracted olive oil.

Keywords: Olivier **(**Olea europaea L.**)**, Provenance, climatic conditions, yield, agroecosystems, semiarid climate.
Abbreviations: ATU_ Agricultural Territorial Unit; CV_ Coefficient of Variation; SD_ Standard Deviation; Ddl_ Degree of Freedom.

Introduction

The olive tree (*Olea europaea* L. ssp. *europaea*) is an emblematic species of Mediterranean cultural history. Its diverse use and significant presence in agricultural systems have made it an economic mainstay and cornerstone of Mediterranean agriculture (Besnard et al., 2018). It is an evergreen tree of medium size, which grows natively in relatively dry and hardy conditions of Mediterranean climate. The olive fruit is the most valuable part due to its ecological, economic and cultural importance. Its many small fruits are rich in oil, which is highly valued for its flavor and health benefits (Rapoport et al., 2016).
This species includes many cultivars, most of which are developed through empirical selection. More than 900 million olive trees grown in the world, where the Mediterranean basin remains its preferred area with nearly 95% of the world's olive groves (Lazzeri, 2009). Morocco is one of the main olive producing countries. It has spread throughout the national territory because of its ability to adapt to various bioclimatic stages, ranging from mountainous areas to arid and Saharan areas (Berrichi, 2002). The olive tree is an integral part of the Moroccan heritage and a fundamental element of the agricultural sector, on a surface of 1,098,000 hectares. The national exploitations have a total production of approximately 1,900,000 tons of olives. The olive tree is the most important fruit sector since it represents 65% of the national tree surface. Its capacity to adapt to all bioclimatic stages and to fight against erosion places it at the top of the fruit speculation among Moroccan farmers in most regions. The processing sector in Morocco includes 11,000 traditional units (maâsras) with a capacity of 270 000 tons/year and 948 modern and semi-modern crushing units with a capacity of 180, 2675 tons/year, and nearly 75 olive canneries with a capacity of 202,954 tons/year. This sector occupies an area of about 82,000 ha with a production of 155,000 tons in Beni Mellal Khenifra in central Morocco (MADRPMEF, 2021).
In recent decades, several research works on climate change predict an increase in average temperatures in Morocco between 2.2 °C and 2.6 °C and an average decrease in rainfall between 9 and 12% by 2050 (Sinan and Belhouji, 2016). The environmental conditions, particularly climate change, are key variables that affect not only the quantity of olives production but also the quality and chemical composition of olive oil from region to region and season to season (Mansouri et al., 2018). In fact, the phytochemical profile of plants, through their secondary metabolism, could

be influenced by the environmental conditions of the provenances combined with intrinsic genetic factors (Ruiz-Rodríguez et al., 2014; Maieves et al., 2015). Rainfall and temperatures are the most important environmental factors affecting olive oil composition during olive growth and ripening (Morelló et al., 2006; Lombardo et al., 2008). However, low spring temperatures can negatively influence flowering stage and subsequently olive yield (Dias et al., 2022). Furthermore, many researches have studied the effect of agricultural territorial area on the specific characteristics of olive oil (Hannachi et al., 2007), as the identification of the geographical olive growing area is a reliable criterion for the veracity of olive oil quality (Arslan et al., 2013). For this reason, the same variety reacts differently to different environmental conditions, resulting in oils with different properties (Madeo et al., 2012). The date of olive harvest is of major interest in determining the quality and quantity of oil produced, including water content, oil content, maturity index, acidity index, peroxide index as well as the composition of olive oil (Ait yacine, 2002; Alowaiesh and al., 2016).

The aim of this research work is to evaluate the production of olives oil and quality of extra virgin olive oil of the Moroccan Picholine variety (PM) grown in the four olive-growing territorial units of the region of Beni Mellal Khenifra in central Morocco with a semi-arid climate, over the four olive-growing seasons 2017-2020. Furthermore, the mechanisms of adaptation of the olive tree to climate change and agroecosystems (ATU) of the region are studied.

Results

Maturity index

The ripeness index reflects the degree of a complex process involving physiological and chemical changes in the olive fruit. The color of the olives changes from green to black during the ripening process. The ripeness index is an indicator used in the selection of the appropriate and optimal time of harvest. The present work was focused on samples harvested in three periods reflecting three different stages of maturity (green, purple and black) during four olive growing seasons (2017, 2018, 2019 and 2020). The results of this index in the four territorial units are presented in Figure 1. During the four years of study, the four territorial units presented relatively identical values of the maturity index at each harvest date. For the first sampling period, the maturity index varied between 1.1 (ATU1) and 1.25 (ATU2), 0.75(ATU1) and 1.3 (ATU4), 1.1(ATU4) and 1.75 (ATU2) and between 0.75 (ATU1) and 1.75 (ATU2) (during 2017, 2018, 2019 and 2020 respectively).

During the second harvest period (four-year-study), it varies between 2 (ATU1) and 2.75 (ATU2) and between 3.25 (ATU1) and 3 .75 (ATU2) (ATU3) and from 3 (ATU1) to 3.5 (ATU2) the. On the other hand, this index varies during the third sampling period between 3.8 (ATU1) and 4.25 (ATU2) for the year 2017, from 3.75 (ATU1) and 4.5 (ATU2) in 2018, while it varies from 4 (ATU4) to 4.5 (ATU2) in 2019 and between 4 (ATU1) and 5 (ATU4) in 2020. The evolution of the maturity index in the four agricultural territorial units studied follows the same pattern during the four years of study.

Water content

Moisture content represents one of the indicators determining the efficiency of olive oil extraction. The results of the water content during the ripening period are presented in Figure 2. The data in this figure show a decrease in the water content of the olive during the ripening period in all the agricultural units during the four years of the study. Nevertheless, the decrease in water content differs from one unit to another. In fact, during the first sampling period the water content varies from 53% (ATU3) to 65% (ATU1), while it varies between 57% (ATU3) and 67% (ATU1), and between 54% (ATU3) and 65% (ATU1) and from 63% (ATU1) to 68% (ATU2) in 2017, 2018, 2019 and 2020, respectively. However, the water content during the second sampling period fluctuates between 43% (ATU3) and 51% (ATU1), from 48% (ATU3) to 57% (ATU2), from 44% (ATU2) to 49% (ATU3) and between 47% (ATU4) and 52% (ATU2) during 2017, 2018, 2019 and 2020, respectively.

In addition, the water content during the third sampling period, varies from 34% (ATU2) to 43% (ATU1), and between 36% (ATU3) and 45% (ATU1), while it is between 35% (ATU2) and 42% (ATU1) and lastly between 37% (ATU3) and 40% (ATU1) during the years of study from 2017 to 2020.

Quantitative characteristics

The analysis of the descriptive statistics of the quantitative characteristics of the olive products of the Beni Mellal-Khenifra region from four different territorial units, shows a variation of characteristics between these provenances (Table 1). In fact, the average olive yield varies from 3.04±1.78 tons/ha (ATU2) to 4.21±1.16 tons/ha (ATU1) with a variation coefficient of 39.38%. A variation in yield within each unit is well noted, with a rate of 58.50% within ATU2 and 49.31% for ATU4. On the other hand, the yield of olive oil varies from 16.50±1.63 liter/qx for ATU2 to 17.52±1.32 liter/qx for ATU1, with a coefficient of variation between units of 9.86%. In fact, ATU1 (Plaine Grande Hydraulique) is the most profitable from the point of view of quantity of olives and olive oil, followed by the ATU3 located in the Piedmont (Dir), while the ATU2 (Bour with private pumping) is the least profitable.

Qualitative characteristics

In addition, the descriptive statistics of the qualitative traits showed significant variation among units (Table 1). Free acidity ranged from 0.83±0.15 for ATU1, with a coefficient of variation of 18.17% within this unit, to 0.98±0.69 in ATU3 (CV=70.40%). The rate of variation of free acidity between units was 42.42%. For the peroxide value, its values ranged from 4.08±3.46 in ATU4 to 6.86±3.18 in ATU3, with a coefficient of variation between units of 54.19%. In addition, the graphical representation of the means of the studied traits (Figure 3) reveals a variation for the qualitative and quantitative traits from one unit to another.

The collection of samples of olives and olive oil was carried out at the level of different agricultural territorial units (agroecosystems) under the region Beni Mellal-Khenifra in central Morocco. This difference is reflected in the yield and quality of olives and olive oils. In fact, the results of the single factor analysis of variance (ANOVA) (Table 2) show that the origin(ATU) of the samples has a significant effect on the yield of olive and olive oil and on the quality of olive oil ($P < 0.05$). This could be explained by the variation of environmental factors, especially climatic, from one agricultural territorial unit to another.

The single factor ANOVA showed the effect of harvest date on the quantitative and qualitative characteristics of olive products of 4 agricultural territorial units of the region of

Beni Mellal-Khenifra (Table 2). It indicates that the period and year of harvest has a significant effect on the quantity of olives and olive oils and on the quality of olive oils, from one agricultural unit to another, in particular, on the yield of olives and olive oils and by less significance on the acidity and peroxide value of oils.
However, the Pearson correlation coefficient (Table 3) shows significant correlations between the climatic conditions of the agricultural territorial units and some qualitative and quantitative characteristics of the olive products of the Beni Mellal-Khenifra region. Indeed, the yield of olives and olive oils presents a significant correlation with the annual average temperature (r=0.803 and r=0.837; P<0.01 respectively). On the other hand, a positive and significant correlation was observed between olive yield and moisture content (r=0.654; P<0.01), while it was negative between the latter and olive oil yield (r=-0.622; P<0.01). These results show that the provenance (ATU) of the samples affects the quantity and quality of olives and olive oils. A positive correlation was observed between free acidity and peroxide value (r=0.467; P<0.01). On the other hand, other correlations were observed, but they were not significant.

Discussion

The importance of the quantity and nutritional value of olive products continues to grow. National and international markets are increasingly aware of the need to ensure the safety of these products in the context of sustainable development. Maintaining good quantities and quality is becoming an increasingly important factor for the actors in this field. To do so, it is essential to identify the factors that influence the quantitative and qualitative properties of these products. The present study is designed to evaluate the effect of the provenance and its environmental factors as well as the harvest date in which the periods of the olive growing season are nested on these characteristics.
Among the factors determining the quantity and quality of olive oils is the maturity index. This index reflects all the physiological and chemical transformations that occur in the fruit (El Qarnifa et al., 2019). The maturity index is used to determine the optimal harvesting period based on the changes in the color of the olive skin (Bengana, 2017). The results of the present study show that the values of this index are the same in all the units studied with slight differences from one year to another. This similarity in MI values could be explained by the fact that the cultivars studied are all of the same variety, Moroccan Picholine. This suggests that the variation in olive oil, quantity, and quality between units is not significantly influenced by the slight difference in olive maturity rate between these units. But by other factors that could be intrinsic or extrinsic such as the adaptive power of the individuals (genotype) to the environmental conditions of the units, the climatic variation from one unit to another and the interaction between these two factors (Rondanini et al., 2014; Gharbi et al., 2015).
On the other hand, the water content, which is one of the important technological criteria inthe olive processing (Dais and Hatzakis, 2013), is inversely proportional to the ripeness index and the oil content. On the other hand, a high-water content in olives can reduce the extraction efficiency and oil quality (polyphenol content) (Bengana, 2017). The results obtained from this work show a decrease in water content in the samples during ripening from the beginning of the olive crop year in the four territorial units and during the four years of study. These results agree with those reported by Brescia and Sacco (2010), Gutierrez-Rosales et al. (2010) and Dag et al. (2011). On the other hand, the water content differs slightly. This could be explained by the variation in the water profile (irrigated/non-irrigated) of the units and their climatic conditions, as well as by the succession of rainfall fluctuations in the study area and the accentuation of drought periods leading to a probable transition from a semi-arid to an arid climate. This means that the water content of olives is dependent on the prevailing environmental conditions in a given area.
To determine the factors affecting the quantity of olives and oil content, as well as the nutritional quality of olive oil, this study was conducted during the period from 2017 to 2020 in the olive growing area of Beni Mellal-Khenifra, known for its topographic diversity. There are three distinct agroecosystems: Plain, Piedmont (Dir) and the Mountain, divided into five Agricultural Surface Units (DRA BK, 2019). The results obtained show that ATU1 has a good yield of olives and olive oil, since the unit is characterized by an annual rainfall of up to 353.42 mm, which proves that olive production is dependent on the water supply provided by winter precipitation, which replenishes soil moisture, through rare summer events or irrigation (Pumo et al., 2016). This unit is thus characterized by an average annual temperature ranging from 11.26 °C to 22.08 °C, favoring maximum flowering in the month of May (Bonofiglio et al., 2008), and allowing for a good oil yield, as the oil content (% dry weight) is influenced by environmental conditions and the fruit ripening index (Rondanini et al., 2011).
Although the ATU2, not equipped by great Hydraulics, the results obtained at the level of this olive territorial unit show a low yield of olives and olive oils compared to the other units, which is due to high temperatures or hot winds that dry out the pollen and stigmas leading to a subsequent reduction in olive yield (Connor and Fereres, 2010). On the other hand, reduced rainfall and increased temperature for this agricultural territorial unit would increase the water stress of the vegetation and decrease the productivity of the olive farms (Viola et al., 2013), and subsequently significantly influence the oil content. In fact, low rainfall can result in lower oil content and higher dry matter content in olives (Salvador et al., 2001). Similarly, the rate of ripening can influence the oil yield as ripening progressed. The oil content gradually increased over the four units, which corroborates the results of other authors (Mahhou et al., 2014).
The ATU3 is the Piedmont area of the Middle Atlas with gentle slopes joins the plain to the north with the northern spillover of the Atlas. The results obtained in this unit are close to those of the ATU1 unit.
However, the ATU4 is characterized by rainfall rates ranging from 193 mm to 490 mm, as well as temperature degrees varying between 20.20 °C and 24.25 °C. The soils are relatively less fertile, consisting of almost continuous outcrops of limestone and dolomite, except in some very localized depressions. These soils are very shallow, except in the lowlands. Olive plantations are often irregular, and the density is less than 100 trees per hectare. This unit ranks behind ATU1 and ATU3 in olive and olive oil production.

Table 1. Quantitative and qualitative characteristics of olive products from the Beni Mellal- Khénifra region from four agricultural territorial units.

ATU		Olive yield T/ha	Oil yield l/qx	Free acidity	Peroxide value
ATU1	*Mean* ± SD	4.21±1.16	17.52±1.32	0.83±0.15	4.39±1.25
	Min -max	2.12-5.80	15.50-19.60	0.51-1.10	2.50-6.50
	CV	27.46	7.53	18.17	28.49
ATU2	*Mean* ± SD	3.04±1.78	16.50±1.63	0.93±0.25	4.82±1.86
	Min -max	0.60-7.00	13.00-19.50	0.44-1.36	2.50-9.00
	CV	58.50	9.87	26.99	38.50
ATU3	*Mean* ± SD	3.81±0.57	17.31±1.73	0.98±0.69	6.86±3.18
	Min -max	3.10-5.00	15.00-21.00	0.28-2.40	2.50-12.00
	CV	14.90	9 .99	70 .40	46.41
ATU4	*Mean* ± SD	3.17±1.56	16.87±2.12	0.88±0.28	4.08±3.46
	Min -max	1.00-7.00	13.00-20.00	0.43-1.35	1.75-15.00
	CV	49. 31	12.59	31.36	84.91
Total	*Mean* ± SD	3.55±1.40	17.06±1.68	0.89±0.38	4.98±2.70
	Min -max	0.60-7.00	13.00-21.00	0.28-2.40	1.75-15.00
	CV	39.38	9.86	42.42	54.19
F-value		2.285**	0.974**	0.566**	2.801**

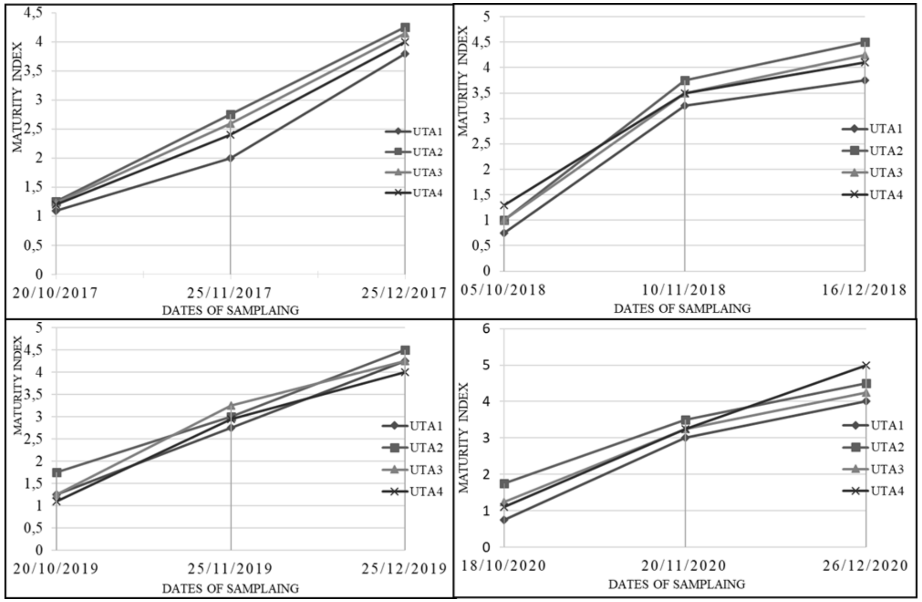

Fig1. Evolution of the maturity index of olives from different olive groves in the agricultural territorial units of the region of Beni Mellal Khenifra during the seasons 2017, 2018, 2019 and 2020.

Table 2. One way ANOVA of the effect of provenance and harvest date on the qualitative and quantitative characteristics of olives and olive oils.

		Sum of squares	Ddl	Average of squares	F	Signification
By ATU	Yield in olives T/ha	12.490	3	4.163	2.285	0.002**
	Oil yield of olives/qx	8.273	3	2.758	0.974	0.003**
	Free acidity	0.305	3	0.102	0.566	0.007**
	Peroxide value in meq of o_2 /kg	70.310	3	23.437	2.801	0.004**
By date of harvest	Olive yieldT/ha	0.869	3	0.290	0.142	0.006**
	Yield in Oil/qx	1.075	3	0.358	0.121	0.008**
	Free acidity in %.	0.506	3	0.169	0.961	0.118
	Peroxide value inmeq of o_2 /kg	35.870	3	11.957	1.324	0.07 7

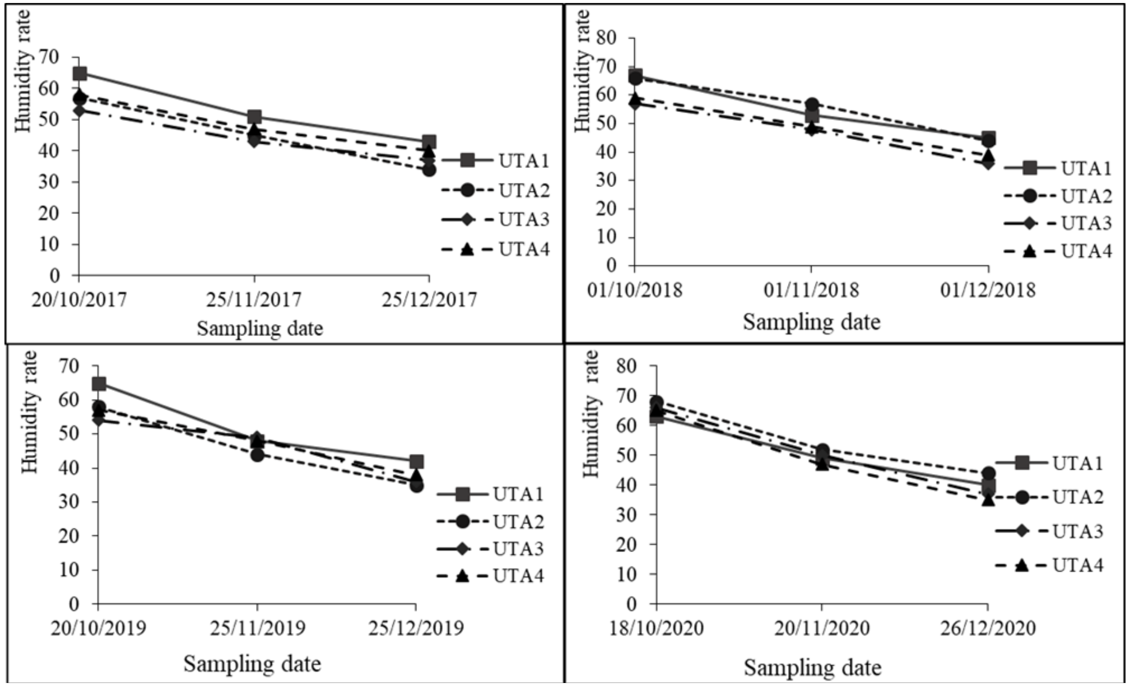

Fig 2. Progression of the state of water content (%) of olives from different olive orchards in the agricultural territorial units of the region of Beni Mellal Khenifra during the seasons 2017, 2018, 2019 and 2020.

Table 3. Correlation between quantitative and qualitative characteristics and climatic conditions of the agricultural territorial units of the region of Beni Mellal Khenifra.

	Annual temperature average °C	Annual precipitation averages in mm	Wind speed inkm/ h	Averageannual temperature of wind in °C	Humidityin %.	Olive yield T/ha	Oil yield l/qx	Free acidity in %.	Peroxide value in meqof o_2 /kg
Average annual temperature °C									
Average annual precipitation in mm	0.173	1							
Average annual windspeed in km/ h	-0.413	0.158	1						
Average annual windtemperature in °C	0,237	.597**	-0.187	1					
Humidity in %.	-0.651	0.120	.566**	-0.226	1				
Yield in olives T/ha	0.803**	-0.077	0.107	-0.045	0.654**	1			
Oil yield l/qx	0.837**	-0.144	0.097	0.069	-0.622**	0.193	1		
Free acidity in %.	0.036	0.106	-0.089	-0.034	0.013	0.143	0.163	1	
Peroxide value in meq of o_2 /kg	0.046	0.238	-0.118	0.064	0.125	0.022	0.172	0.467**	1

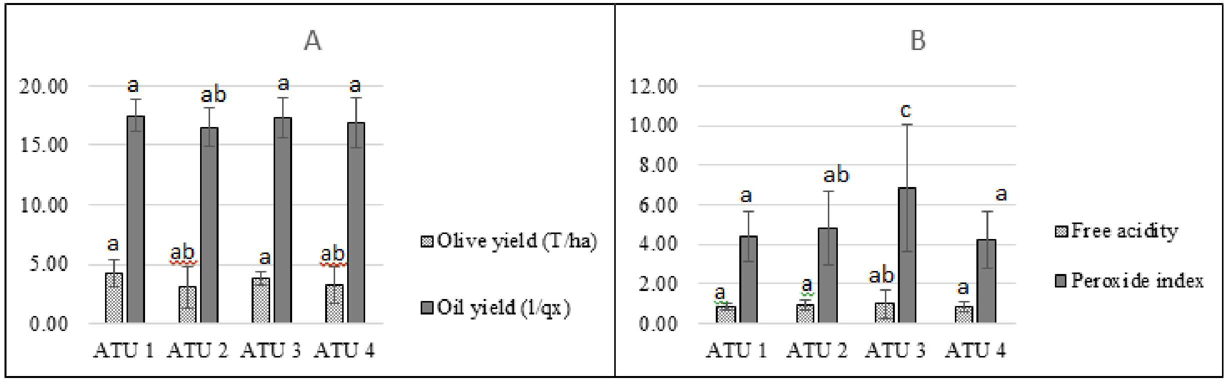

Fig 3. Variation of quantitative (A) and qualitative (B) characteristics of olive products in the Beni Mellal-Khénifra region during the 2017, 2018, 2019 and 2020 seasons.

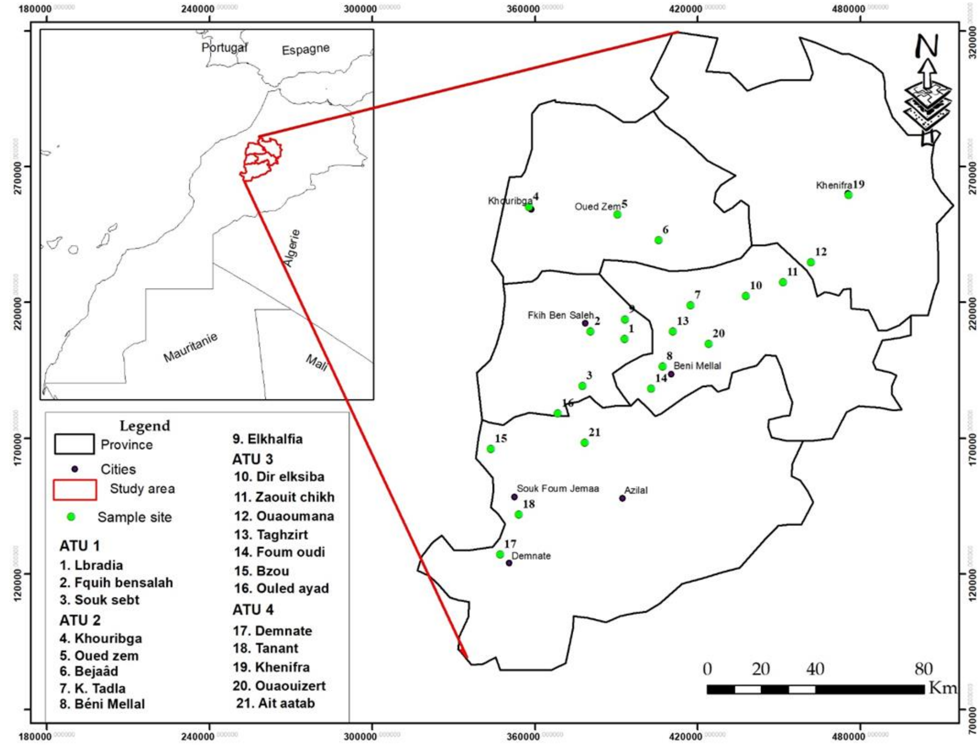

Fig 4. Regional geographic location of the study area and delineation of agricultural territorial units.

the results confirm that olive oil yield is reduced by warming during the oil accumulation period, from final fruit set to harvest (Miserere et al., 2022). On the other hand, the effect of the date of harvest is considered a major factor in the variation of the quantity and quality of olive oil (Rotondi et al., 2004). As well as the variation of the yield and quality of oils between the years of study is explained by fluctuations in climatic conditions that occur from year to year and particularly by the succession of periods of drought that the country has experienced in recent years, especially the region Beni Mellal-Khenifra where the present work is carried out.

On the other hand, the qualitative parameters are also influenced by the provenance of the samples, moving from one unit to another, which proves that the physiological mechanisms of plants are influenced by the change of environmental conditions. Furthermore, plants respond to their environment including biotic and abiotic factors that regulate the biosynthesis of their secondary metabolites (Zhi-lin et al., 2007; Osama, 2018). Also, the harvest date carries an impact on the quality of olive oils, but in a less significant way than the effect of provenance, where the harvest period is determined by the maturity rate of olives (Rotondi et al., 2004; Bengana, 2017). Therefore, the choice of the right harvest period is essential to ensure a good quality olive oil.

However, the values obtained for the qualitative parameters, free acidity and peroxide index, classify the oil of four units in the virgin to extra virgin category. In addition, the peroxide index recorded lower values than those reported by Meftah et al. (2014) in the same region, by Boulfane et al. (2015) in the Chaouia region and by Salvador et al. (2003) for olive oil from Spain. Nevertheless, this index shows a remarkable difference between the units studied, suggesting that the origin of the samples is at the origin of this difference. Similarly, the free acidity expressed as a percentage of oleic acid shows values below 1%. Therefore, according to the commercial standard of the International Olive Oil Council (IOOC, 2011), it is found that all the samples from the different units are extra virgin type. These results are in agreement with those reported by Tanouti et al. (2010) who noted that the free acidity of oils from Eastern Morocco was about 0.8%. The units studied show significant differences in free acidity values. This difference could be explained by the difference in the origin of the samples (ATU).

In addition to the effect of the origin, other factors may be responsible for the difference in quality of olive oil between the four units. One of these factors is the harvest date, which is determined by the maturity rate of the olives. According to Mendoza et al. (2013), acidity increases progressively as the olives ripen. This could be explained by an increase in lipolytic activity, as well as an increased susceptibility of olives to pathogenic infections and mechanical damage (Anastasopoulos et al., 2011; El Qarnifa et al., 2019). In addition, the peroxide value showed low values at full maturity, which could be explained by a decrease in lipoxygenase activity at full maturity of olives (Baccouri et al., 2008; El Qarnifa et al., 2019).

These results are supported by a single factor analysis of variance (ANOVA) and by the correlation between the quantitative and qualitative parameters of the olive products and the environmental factors of the territorial units of the Beni Mellal-Khenifra region. This shows that the variation in the quantity and quality of olive oil between these units depends on environmental and especially climatic profiles of each unit. Therefore, extreme variations in these conditions could act on the phenotypic plasticity of olive trees.

Materials and Methods

The present study aims to evaluate the effect of the origin on the quantity and quality of olive products. We have focused on four seasons from 2017/2018 to 2020/2021, which are characterized by a remarkable climate change. During this period, we conducted the analyses in the field and in the laboratory for samples coming from four agricultural units of the Beni Mellal-Khénifra region (semi-arid climate). In fact, we treated the effect of pedoclimatic conditions, namely, the temperature and the annual precipitation rates and the harvesting period on the productive (quantitative) potentialities of the Moroccan Picholine variety, namely, the production of olives and olive oil and the qualitative characteristics, particularly the free acidity and the peroxide index.

Study area and sampling

The Moroccan picholine is the most dominant variety in the study area. It constitutes 78% of the total area under olive cultivation in the different agroecosystems (ATU) of the Beni Mellal-Khenifra region (Figure 4). The territorial units were classified according to their topographic profile and pedoclimatic parameters (Tables 4 and 5). The fruit samples were taken during the four years of study at three different dates in the four agricultural territorial units of the Beni Mellal-Khenifra region (Table 4). The first was between October 5 and 20 where most of the fruits were green, with scarlet skin and green flesh. The second was between November 10 and 25 where most of the fruits were purple green, with white flesh. The last was between December 16 and 26 where the fruits were almost all black.

Maturity index

The maturity index is determined based on the evaluation of the color of 100 olives taken randomly from a 1 kg sample, according to the method proposed by Uceda and Frias (1975). These olive samples are divided into 8 classes, ranging from olives with intensely green or dark green skin to oliveswith black skin and completely dark flesh. The maturity index is calculated using the following formula:

$$\boldsymbol{Maturity\ index} = \frac{\left((\mathbf{0}\times \boldsymbol{n0}) + (\mathbf{1}+\boldsymbol{n2}) + (\mathbf{2}+\boldsymbol{n2}) + \cdots + (\mathbf{7}+\boldsymbol{n7})\right)}{\mathbf{100}}$$

With: n0, n1,..., n7 : the number of the solves of the following classes :

- 0: olives with intense green or dark green skin.
- 1: olives with intense yellow or yellowish epidermis.
- 2: olives with yellowish epidermis, with reddish spots or areas.
- 3: olives with reddish or light purple epidermis.
- 4: olives with black epidermis and completely green pulp.
- 5: olives with black skin and purple pulp up to half its thickness.
- 6: olives with black skin and purple pulp up to the pit.
- 7: olives with black skin and completely dark pulp.

Water content of samples

The moisture content of the olives was determined on 50 g samples of crushed fruit. They were taken and weighed (fresh weight). They were then dried in an oven set at 105°C for 48 hours or until the weight was stabilized. At the exit of the oven, the residues are weighed (dry weight). The humidity in % (m/m) was calculated by the relation:

$$\mathbf{M}\boldsymbol{oisture}\ \%(\boldsymbol{m/m}) = \left(\frac{(\boldsymbol{Fresh\ weight} - \boldsymbol{dry\ weight})}{\boldsymbol{fresh\ weight}}\right) \times \mathbf{100}$$

The moisture content tests were repeated three times.

Quantitative characteristics

Olive yield

The olives were harvested by hand on 10 trees selected per hectare following a "Z" shaped tracing in each plot (1ha) located in each ATU. Harvesting was done at man's height and at the four cardinal points of the tree, according to the optimal date of harvest (Ait Yacine, 2002). The cultivars were harvested entirely, except the 10 trees that were the subject of the three samples. The measurements were carried out over a period of 4 years (2017-2020). The well-homogenized fruits were transported in aerated plastic boxes and then washed. The average tree yield obtained each year was calculated using the Pearce and Dobersek-Urbanc (1967) formula:

$$\boldsymbol{AB} = \left(\frac{\mathbf{1}}{\boldsymbol{n}-\mathbf{1}}\right)\left((\boldsymbol{a2}-\boldsymbol{a1})/(\boldsymbol{a1}+\boldsymbol{a2})\right) + \left((\boldsymbol{a3}-\boldsymbol{a2})/(\boldsymbol{a3}+\boldsymbol{a2})\right) + \left((\boldsymbol{a4}-\boldsymbol{a3})/(\boldsymbol{a4}+\boldsymbol{a3})\right)$$

Where ***n*** is the number of years of evaluation; a1, a2, a3, and a4 represent the olive production per tree obtained each year (2017-2020).

Olive oil yield

After harvesting, the olives were transformed into oil within 24 hours using the Abencor system. Only healthy fruit was extracted without physical damage. The olives were peeled and crushed with a hammer mill and the resulting olive paste was kneaded at 26°C for 30 min. The oil was centrifuged for 1 min at 3500 ppm. After filtration, the olive oil samples were transferred to dark glass bottles and stored without headspace before analysis (Rouas et al.,2015).

Qualitative characteristics

Free acidity

The free acidity, expressed as percentage of oleic acid, was determined on a test sample of 1g of olive oil dissolved in 50 ml of ethanol. The mixture was titrated with 0.1 N potassium hydroxide solution in the presence of phenolphthalein (ISO 660:2009(E), 2009; Boulfane et al., 2015).

Peroxide value

The evaluation of the peroxide value was performed according to the method described by ISO 3960 (2007) as follows: 1g of olive oil is dissolved in 12.2 ml of a 3: 2 (v/v) acetic acid/chloroform mixture. 15 ml of a saturated potassium iodide solution is added to the mixture. The latter is placed in the dark for 5 min. Then 60 ml of distilled water and 1 ml of a starch solution are added (a purple color appears). The resulting mixture is titrated with a 0.01N sodium thiosulfate solution (ISO 3960:2007(E), 2007; Boulfane et al., 2015).

Data analysis

The data obtained were subjected to statistical analysis. Thus, the descriptive statistics aimed to evaluate the mean, standard deviation and coefficient of variation of the olive yield and olive oils, as well as the qualitative characteristics of olive oils. The single-factor analysis of variance (ANOVA), as well as the Pearson correlation test between quantitative and qualitative characteristics and environmental factors were used to determine the factors that influence the variation of olive oil yield and quality between the agricultural territorial units (ATU). These analyses were performed by IBM SPSS Statistics for Windows software, version 20.0 (2011).

Conclusion

The present study has shown that the origin and the date of harvesting could influence the olive and olive oil yield and the food quality of olive oils. In fact, the results obtained show a variation in the yield of olives and olive oils between the agricultural territorial units, as well as a variation in the qualitative parameters, namely, free acidity and peroxide value, from one unit to another. In addition, the analysis of variance (ANOVA) with a single factor showed that the origin and the date of harvest have a very significant effect on the quantity and quality of olive products in the region Beni Mellal-Khenifra. On the other hand, the Pearson correlation coefficient showed a significant relationship between these parameters and some environmental factors characterizing the agricultural units. These results could be exploited as a database for further studies in order to identify all the factors that can improve the quantity and quality of olive products within the framework of a sustainable development, as well as to customize the cultivation of the most profitable and adaptive varieties for the environmental conditions of each unit.

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