ABSTRACT: Trees of the olive (Olea europaea L.) cultivar Zalmati grown in Zarzis (Mednine) with different main climate traits (temperature, precipitation, humidity, and wind) were studied for 3 years to evaluate the impact of climate on the quality of olive oil. The effect on quality indices, free fatty acids, peroxide value, UV spectrophotometry, pigment content, and phenol and O-diphenol concentrations, of the three harvesting periods was considered. Linking to the purity parameters (fatty acid, triacylglycerol, total phenols, and tocopherols composition), our results showed a trivial reduction in fatty acid composition and polyphenols content caused by the high temperature. In fact, precipitation strongly affects the pigment content, which showed a significant decrease during rainy seasons. Nevertheless, principal component analysis allowed us to highlight the correlation between parameters and indicates that 57.8% of the variation of monounsaturated fatty acids (MUFAs), polyunsaturated fatty acids (PUFAs), MUFA/PUFA, α-tocopherol, C18:1, and C18:2 amounts was explained by the mean temperature.

1. INTRODUCTION

Climate change, which includes variations in temperature, precipitation, humidity, wind, and atmospheric composition, epitomizes a moving target for plant developmental adaptation. Besides, human activities including fossil fuel combustion and deforestation have augmented the concentration of greenhouse gases in the atmosphere, resulting in climate warming and perturbations of hydrological cycles. The olive tree (Olea europaea L.) is the symbolic plant in terms of oil-producing crops in the Mediterranean basin. At present, the world’s olive fruit production is estimated to be about 19 million tons, 90% of which is consumed as olive oil and 10% as table olives. Olive tree biodiversity is estimated to have more than 1200 cultivars, which is a large amount of genetic variation. Olive trees have nowadays expanded to many countries in the world, adapting to many microclimates that typify each region. Given the promotion of olive oil as a product with both nutritional and health benefits, the cultivation of the olive tree has grown across Asia, America, and Oceania.

The climate of the region is continental Mediterranean, with warm summers and lengthy, cold winters. Due to its proximity to the Mediterranean Sea, this area is distinguished from other olive-growing locations with a more temperate climate by the significant thermal variation between winter and summer, with yearly minimum temperatures of −8 °C and maximum temperatures exceeding 40 °C. In this area, rainfall is limited and erratic, whose amounts are higher in spring and lower in summer (July) and winter (January and February). The rainfall pattern differs from one year to another, which is a characteristic of the Mediterranean climate. Taking into account all these climatic factors, olive trees are proven to be tougher and can thrive on many different terrains and under various climatic conditions. Tunisia, for example, is a suitable case study for regional data because its climate is highly diversified, with extremes ranging from Saharan climate in the south to European climate in the north.¹ Tunisia is considered one of the driest regions in the world: only 30% of the cultivated area in the region is irrigated but produces about 75% of total agricultural production. The average yearly temperature in the south is 35 °C, whereas in the north, it is 20 °C. The weather in the country’s center appears to be Mediterranean. The olive tree (Olea europaea L.) is Tunisia’s most important evergreen tree, with 60 million trees spanning 1.6 million hectares.² It is usually grown in rain-fed conditions. Olive oil has gained popularity in recent years as a result of its antioxidant and health-promoting characteristics. Actually, in the past years, there has been a wide

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range of climatic conditions, allowing researchers to investigate their effects on virgin olive oil composition and quality indices as well as those of the damage to oil quality. The latter emanates from the freezing of olives, which is a source of concern in this area where high-quality oils are produced. The sensory features that play an essential role in the organoleptic characteristics and antioxidant capabilities of virgin olive oils and the changes in minor components such as chlorophylls, carotenoids, and phenolic compounds are of particular interest.

An overview of the literature reveals that several studies on Spanish and other Tunisian cultivars have been carried out. Indeed, some research works have presented information about the fatty acid composition and changes of antioxidant compounds according to macroclimatic conditions. Only a few research studies, however, considered the impact of the macro- and mesoclimatic environments on olive water and oil content and oil quality parameters such as fatty acid profile, polyphenols, and induction time. It is also trusty to mention that studies on the effects of seasonal climatic factor variations on “Chemlali” olive oil quality are scarce.

In addition, various studies pertaining to monovarietal virgin olive oils have demonstrated that rainfall, in particular during the growing and ripening of the olive fruit, is one of the most substantial environmental factors that greatly impact the oil composition, primarily the minor components, of virgin olive oils. When studied over four consecutive seasons, the monovarietal virgin olive oils obtained from the Arbequina cultivar growing in the area of the Protected Designation of Origin “Les Garrigues” (Catalonia, Spain) indicated a great impact of climatic conditions. Low temperatures during the olive harvest season influenced the levels of chlorophyll, carotenoid pigments, and α-tocopherol, whereas cumulative rainfall during the summer period influenced the composition of fatty acid and phenolic components. The present research work undertook an exploration on an olive cultivation area in Zarzis (southern Tunisia). Its utmost objective is to identify the effect of the climatic conditions of the olive crop season on the composition of monovarietal virgin olive oils, with special emphasis on the phenolic fraction, including tocopherol, fatty acid, and triacylglycerol composition, as well as related oil quality parameters, such as oxidative stability (OS) and the sensorial assessment.

2. MATERIALS AND METHODS

2.1. Study Site. The experimental site, Zarzis, belonging to the governorate of Medenine is located in the south-east of Tunisia, in which the olive grove has about 4650 million olive trees on an area of 188,250 ha. The site under investigation belongs to the Mediterranean arid bioclimate. Its climate is characterized by hot and dry summers and a relatively cold winter (the temperature varying between 7.5 to 18.5 °C in winter and 22.5 and 36 °C in summer). The annual precipitation is very irregular, varying from one year to another (rainfall is variant between 100 and 200 mm).

The study area from which we took our samples is located in the station of Chammakh, where the majority of olive trees are dry-planted, resulting in fluctuation in the production from one year to another due to the annual variability in precipitation and the biological phenomenon of alternating olive trees.

The “Chammakh” zone represents the following geographical situation:

Longitude: 11°00’50.40’’E.
Latitude: 33°35’42.42’’N.
Altitude: 14 m.
Therefore, the olive grove of the governorate of Medenine is largely subject to the effects of drought, which characterizes the climate of the region. It is also likely to worsen under the effect of climate change as climate projections predict a significant decrease in rainfall and a substantial increase in temperature for the southern region of the country. To this end, the Institute of Arid Regions (IRA) has a reasonably dense meteorological station network, consisting of 12 automatic stations spread over many arid regions of southern Tunisia. Precipitation, air temperature, relative humidity, global solar radiation, wind speed, and direction are all measured by these stations.

2.1. Climate. The climate data of the experimental site “Zarzis”, including monthly precipitation (mm), monthly average relative humidity (%), monthly average temperatures (°C), and monthly mean wind, in the experimental period of 2018–2020 are summarized in Figures 1 and 2.

Figure 2. Monthly mean wind (m/s) registered at the experimental farm during three crop seasons.

These data show that Zarzis climate is characterized by hot temperature in summer, dry winds, and strong precipitation, especially from November to March. The average humidity is extensive, reaching 80% at the beginning of the year 2020.

2.1.2. Olive Sampling. This study was carried out on the samples of Zalmati olives, and trees were grown in the region of Medenin: Zarzis (see Section 2.1). The olives were harvested in excellent clean conditions from the same trees planted in similar pedoclimatic conditions, during three crop seasons 2018/2019, 2019/2020, and 2020/2021. Only healthy fruits from each age category were processed during different ripening stages. Olives were collected during the maturation process on the basis of their maturation index, from the beginning of the harvest period, when the fruits are green, until the end of maturity, when fruits are back. After harvesting, the collected samples (2 kg of olive fruits for each sample) were transported to the laboratory of olive institute. Olives were crushed with a hammer mill and slowly mixed for 30 min at 25 °C. Then, the obtained paste was centrifuged at 3500 rpm over 3 min. The oil samples were directly stored in the dark at 4 °C until analysis.

2.2. Determination of Maturation Index. The determination of maturation index (MI) which varied between 0 (100% intense green skin) and 7 (100% purple flesh and black skin) followed the method developed by the agronomic station of Jaen by evaluating the color of the skin and pulp of 100 olives that were randomly chosen.

2.3. Virgin Olive Oil Quality Indices. Free acidity, expressed as oleic acid percentage in the oil (g/100 g), was realized according to the method proposed by ISO (660: 1996). The peroxide value (meq O₂ kg⁻¹) was determined according to the method proposed by ISO (3960: 2001), and UV absorption at 232 and 270 nm (K₂₃₂ and K₂₇₀) was realized following the International Olive Council (IOC) standard (IOC, 2019). Subsequently, chlorophylls and carotenoids (mg/kg of oil) were determined at 670 and 470 nm, respectively, in cyclohexane using the specific values according to the method described by Haddada et al. As for the total phenols, the determination was performed by means of the Folin-Ciocalteu reagent using the method described by Gargouri et al. Moreover, gallic acid was applied as the standard reference, and the results were expressed as gallic acid equivalents (mg/kg). Next, the concentration of O-diphenols was determined by the method adopted from Gargouri et al. The content was expressed as mg/kg of gallic acid. However, the determination of the radical scavenging activity was tested by measuring the decrease in the absorption at 517 nm of DPPH solution after the addition of the antioxidant solution. In a cuvette, 0.25 mL of the extract solution was mixed with 0.5 mL of methanolic solution containing DPPH radicals (6.10⁻⁶ M), and the absorption was monitored at intervals of 15 s for 5 min. The resulting difference is expressed as the percentage (percentual reduction) of scavenged radicals.

2.4. Oil Stability. A Metrohm Rancimat model 743 (Herisau, Switzerland) was used. The tests were carried out with 5.0 g of oil. All samples were studied at 120 °C with a continuous air flow of 20 L/h passing through the samples. The conductivity cells were filled with 60 mL of deionized water. The oxidative stability is defined as the time, expressed in hours, which is needed to reach the maximum change of conductivity.

2.5. Fatty Acid Composition. Fatty acid composition of olive oil samples was identified using a gas chromatography system (HP 6890, Agilent Technologies, DE, USA) equipped with a flame ionization detector (FID), as described by International Olive Council (IOC) (2013). A capillary column (DB-23, 30 m × 0.25 mm × film thickness: 0.250 µm, Agilent J&W GC Columns, DE, USA) was used for the analysis. The detector and injector were both set to a temperature of 250 °C. In addition, the oven temperature was programmed from 170 to 210 °C with an increment of 2 °C/min. The analysis was completed by keeping the temperature to 210 °C for 10 min. A volume of 1 µL of injection was used. By comparing the retention durations of the peaks to those of authentic reference substances, the peaks were recognized. The fatty acid composition was estimated using the internal normalization of the chromatographic peak area and expressed as relative percentages of each fatty acid.

2.6. Triacylglycerol Analysis. The TAGs were analyzed using the approved liquid chromatographic method defined in the European Union Commission Regulation EEC/2568/91. The chromatographic analysis was performed by means of an Instrument Agilent 1200 HPLC system consisting of a degasser, a quaternary pump, a manual six-way injection valve, a differential refractometer detector, and Chemstation software (3365 version) package for instrument control, data acquisition, and data analysis. In fact, the column was a Superspher 100 RP-18 HPLC column (Merck, Germany) (250 × 4 mm i.d. × 4 lm). A loop with a capacity of 100 L, in which 0.5 L of sample was injected, was used. Acetone (63.6%)/acetoneitrile (36.4%) were used as mobile phases with a linear gradient flow rate (1.200 mL/min) under a nebulizer gas pressure of 2.00 bar for 45 min. All solvents were of HPLC grade. The results were expressed in percentage of the total TAG and separated according to the
Table 1. Characteristic Parameters of Zalmati EVOO during Three Consecutive Crop Seasons

| MI | 2018/2019 | 2019/2020 | 2020/2021 |
|----|-----------|-----------|-----------|
|    | 1.23      | 2.12      | 2.8       | 3.17      | 3.85      | 4.18      | 0.89      | 3.07      | 4.7       | 5.2       | 2.89      | 3.05      | 3.24      | 4.17      | 5.56      |
| acidity (% oleic acid) | 0.24 ± 0.05 | 0.28 ± 0.05 | 0.31 ± 0.05 | 0.18 ± 0.05 | 0.2 ± 0.05 | 0.65 ± 0.02 | 0.53 ± 0.01 | 0.33 ± 0.05 | 0.57 ± 0.02 | 0.34 ± 0.03 | 0.29 ± 0.04 | 0.28 ± 0.03 | 0.27 ± 0.04 | 0.55 ± 0.08 | 0.35 ± 0.02 |
| PV (meq O₂/kg) | 11.35 ± 0.07 | 15.14 ± 0.2 | 13.59 ± 0.2 | 14.53 ± 0.1 | 16.33 ± 0.2 | 14.8 ± 0.1 | 8.44 ± 0.03 | 9.94 ± 0.1 | 14.5 ± 0.09 | 11.83 ± 0.04 | 11.5 ± 0.09 | 7.5 ± 0.2 | 15.0 ± 0.2 | 15.0 ± 0.08 | 9.0 ± 0.1 |
| K₅₃₂ | 2.42 ± 0.11 | 2.62 ± 0.00 | 2.59 ± 0.01 | 2.75 ± 0.00 | 2.52 ± 0.12 | 2.47 ± 0.21 | 2.51 ± 0.01 | 2.29 ± 0.12 | 2.76 ± 0.19 | 2.16 ± 0.05 | 2.37 ± 0.2 | 2.15 ± 0.11 | 2.69 ± 0.09 | 1.8 ± 0.09 | 2.36 ± 0.02 |
| K₇₅₀ | 0.15 ± 0.01 | 0.11 ± 0.01 | 0.14 ± 0.01 | 0.17 ± 0.01 | 0.12 ± 0.00 | 0.15 ± 0.00 | 0.075 ± 0.01 | 0.095 ± 0.00 | 0.16 ± 0.03 | 0.132 ± 0.00 | 0.072 ± 0.02 | 0.06 ± 0.01 | 0.84 ± 0.00 | 0.072 ± 0.02 | 0.098 ± 0.01 |
| chlorophyll (mg/kg) | 19.54 ± 1.00 | 11.68 ± 0.07 | 9.13 ± 0.02 | 6.65 ± 0.43 | 5.20 ± 0.57 | 3.18 ± 0.32 | 10.97 ± 0.02 | 6.97 ± 1.5 | 4.14 ± 0.68 | 3.97 ± 0.01 | 15.12 ± 1.42 | 7.80 ± 1.91 | 5.99 ± 1.04 | 4.24 ± 0.71 | 3.36 ± 0.03 |
| carotenoids (mg/kg) | 7.21 ± 0.09 | 2.61 ± 0.09 | 2.77 ± 0.33 | 2.42 ± 0.15 | 1.30 ± 0.25 | 1.13 ± 0.08 | 3.23 ± 0.11 | 2.02 ± 0.11 | 2.24 ± 0.2 | 1.44 ± 0.04 | 5.18 ± 0.36 | 1.55 ± 0.19 | 2.27 ± 0.37 | 1.07 ± 0.1 | 1.55 ± 0.2 |
| total phenols (mg/kg) | 283.62 ± 31.24 | 86.16 ± 4.26 | 94.75 ± 8.32 | 45.56 ± 2.64 | 136.59 ± 8.0 | 43.83 ± 5.94 | 246.97 ± 20.16 | 302 ± 1.02 | 139.83 ± 13.24 | 190.86 ± 2.81 | 71.78 ± 4.10 | 199.67 ± 19.06 | 182.37 ± 50.16 | 357.83 ± 26.32 | 35.98 ± 1.03 |
| O-diphenols (mg/kg) | 8.66 ± 0.08 | 6.89 ± 0.66 | 7.41 ± 0.44 | 2.2 ± 0.41 | 7.91 ± 0.03 | 1.62 ± 0.44 | 8.44 ± 0.02 | 10.55 ± 0.39 | 8.1 ± 0.1 | 8.14 ± 0.64 | 5 ± 0.03 | 8.28 ± 0.52 | 7.98 ± 1.03 | 11.58 ± 0.59 | 1.1 ± 0.37 |
| IC₅₀ | 5.46 ± 1.58 | 19.8 ± 2.07 | 18.3 ± 1.88 | 42.6 ± 2.7 | 12.7 ± 1.8 | 38.6 ± 2.68 | 8.34 ± 1.78 | 6.95 ± 1.22 | 11.5 ± 1.21 | 9.78 ± 2.02 | 29.3 ± 2.33 | 8.35 ± 1.76 | 10.25 ± 1.27 | 5.07 ± 1.9 | 51.5 ± 2.7 |
| stability (h) | 8.4 ± 1.16 | 5.2 ± 1.11 | 5.29 ± 0.54 | 3.4 ± 1.18 | 5.4 ± 1.02 | 4.51 ± 0.15 | 8.12 ± 1.55 | 8.8 ± 1.27 | 6.33 ± 0.92 | 7.5 ± 1.52 | 5.03 ± 1.36 | 7.69 ± 1.10 | 6.9 ± 1.38 | 9.56 ± 0.68 | 3.31 ± 0.72 |
Table 2. Fatty Acid Composition (%) of Zalmati EVOO during Three Consecutive Crop Seasons

| MI     | 2018/2019 | 2019/2020 | 2020/2021 |
|--------|-----------|-----------|-----------|
| C14:0  | 0.01 ± 0.01 | 0.01 ± 0.01 | 0.01 ± 0.01 |
| (C16:0)| 20.56 ± 0.00 | 20.5 ± 0.00 | 20.28 ± 19.15 |
| (C16:1)| 2.39 ± 0.00 | 2.46 ± 0.00 | 2.46 ± 0.00 |
| (C17:0)| 0.04 ± 0.00 | 0.04 ± 0.00 | 0.04 ± 0.00 |
| (C17:1)| 0.05 ± 0.00 | 0.06 ± 0.00 | 0.06 ± 0.00 |
| (C18:0)| 2.87 ± 0.00 | 2.45 ± 0.00 | 2.45 ± 0.00 |
| (C18:2)| 17.85 ± 0.00 | 18.26 ± 0.00 | 20.3 ± 0.00 |
| (C18:3)| 0.60 ± 0.00 | 0.61 ± 0.00 | 0.63 ± 0.00 |
| (C20:0)| 0.47 ± 0.00 | 0.45 ± 0.00 | 0.41 ± 0.00 |
| (C20:1)| 0.17 ± 0.00 | 0.16 ± 0.00 | 0.16 ± 0.00 |
| (C22:0)| 0.11 ± 0.00 | 0.09 ± 0.00 | 0.08 ± 0.00 |
| (C24:0)| 0.05 ± 0.00 | 0.07 ± 0.00 | 0.08 ± 0.00 |
| SFA    | 24.11 ± 0.03 | 23.63 ± 0.02 | 24.9 ± 0.05 |
| MUFA   | 57.05 ± 0.00 | 57.35 ± 0.02 | 58.83 ± 0.04 |
| PUFA   | 18.55 ± 0.02 | 18.87 ± 0.00 | 20.66 ± 0.06 |
| MUFA/  | 0.76 ± 0.00 | 0.79 ± 0.00 | 0.87 ± 0.05 |
| MUFA    | 3.07 ± 0.00 | 3.04 ± 0.00 | 2.73 ± 0.00 |
| MUFA/   | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 |

2.7. Tocopherol Analysis. Alpha tocopherol analysis was realized following the methods given by Carpenter and IUPAC (1987). The performance of the HPLC system (Agilent 1100) was conducted for the analysis with a µ-porasil column (250 mm × 4.6 mm × 5 µm) (Waters, Ireland). The mobile phase consisted of hexane/2-propanol (99:1) and used in the system at a flow rate of 1 mL/min. The column temperature was set to 25 °C, and the injection volume was 20 μL.

2.8. Sensory Evaluation. The sensory profiling was conducted by the Tunisian National Office of Oil Panel according to the official techniques of IOC (2018) and the guidelines for the accomplishment of requirements of standard ISO 17025 of sensory testing laboratories with particular reference to virgin olive oil. The panel was made up of eight judges, five of whom were males and three females between 35 and 55 years, who were fully trained in the virgin olive oil assessment. A tasting glass was filled with 15 mL of each olive oil sample. The samples were held at a constant temperature of 28 ± 2 °C. According to the IOC, there are two sets of descriptors for virgin olive oil: three positive traits, such as fruity, bitter, and pungent and several negative attributes such as fusty/muddy sediment, musty/humid/earthy, winey-vinegary, acid-sour, rancid, and frostbitten olives (wet wood). Other negative characteristic attributes may also have existed, namely metallic, cucumber, greasy, vegetable water, heated, or burnt... For our case, six descriptors were sensed, namely fruity, bitter, pungent, rancid,usty, and winey-vinegary were assumed in the samples under study.

2.9. Statistical Analysis. The nonstandardized principal component analysis (PCA) was carried out by means of both Varimax rotation and Kaiser normalization. The PCA matrix was applied to show the effect of all the investigated parameters (the pigment contents (chlorophylls and carotenoïds), maturity index, α-tocopherol, o-diphenol, stability, IC50, C 18:1, C 18:2, C 18:3, polyunsaturated fatty acid (PUFA)/saturated fatty acid (SFA), monounsaturated fatty acid (MUFA)/PUFA, MUFA, and PUFA) on the olive oil samples. Besides, the PCA type was Pearson (n), the biplot type was correlation biplot, and the coefficient was automatic. The statistical analyses were carried out by SPSS 20.0 for Windows (SPSS, IBM, 20).

3. RESULTS AND DISCUSSION

3.1. Climatic Conditions. Figures 1 and 2 show the trends of annual temperature, rainfall, humidity, and wind during the three consecutive seasons, 2018/2019, 2019/2020, and 2020/2021, which are characterized by relatively mild winters with rare precipitation and abundant humidity, as well as by hot and dry summers. The rainfall amount was significantly high at the autumnal period, particularly in the 2020/2021 crop season, reaching 96.3 mm in November and 73.2 mm in December, as compared to the season 2019/2020 which recorded only 16.6
Table 3. Triglyceride Composition of Zalmiti EVOO during Three Consecutive Crop Seasons

| MI   | 2018/2019 | 2019/2020 | 2020/2021 |
|------|-----------|-----------|-----------|
| LLL  | 0.12 ± 0.14 | 0.22 ± 0.20 | 0.27 ± 0.27 |
| LON  | 0.38 ± 0.52 | 0.63 ± 0.58 | 0.50 ± 0.50 |
| POL  | 0.02 ± 0.06 | 0.01 ± 0.04 | 0.05 ± 0.04 |
| PLL  | 0.43 ± 0.46 | 0.52 ± 0.56 | 0.56 ± 0.56 |
| OLL  | 4.73 ± 5.78 | 6.56 ± 7.09 | 6.94 ± 6.81 |
| OLoO | 1.35 ± 1.29 | 1.77 ± 1.53 | 1.70 ± 1.72 |
| PLL  | 3.02 ± 3.76 | 4.43 ± 4.39 | 4.05 ± 4.03 |
| OLO  | 1.28 ± 1.35 | 1.23 ± 1.38 | 1.34 ± 1.34 |
| LOO  | 13.82 ± 13.91 | 14.29 ± 15.29 | 16.57 ± 16.65 |
| PlPe  | 0.02 ± 0.04 | 0.10 ± 0.07 | 0.28 ± 0.34 |
| POO  | 1.93 ± 2.33 | 2.17 ± 2.80 | 2.17 ± 1.93 |
| PLO  | 14.06 ± 15.71 | 16.50 ± 15.69 | 15.13 ± 15.47 |
| PSL  | 0.00 ± 0.04 | 0.03 ± 0.04 | 0.04 ± 0.02 |
| PoO  | 1.83 ± 1.78 | 1.56 ± 1.48 | 1.42 ± 0.58 |
| PLL  | 2.50 ± 2.73 | 2.90 ± 2.75 | 2.73 ± 2.43 |
| OOO  | 17.74 ± 16.14 | 15.20 ± 18.50 | 17.46 ± 17.28 |
| SLO  | 23.96 ± 22.49 | 21.34 ± 20.55 | 19.98 ± 20.48 |
| SOO  | 3.35 ± 3.10 | 2.95 ± 2.78 | 2.78 ± 2.74 |
| SOO  | 1.92 ± 1.76 | 1.68 ± 1.59 | 1.38 ± 1.34 |

and 27.2 mm for November and December, respectively. The summer and autumnal periods (May–September) were characterized by a significantly high temperature. Humidity exists throughout the year in high amounts. The crop season 2020/2021 possesses lower levels of wind, particularly from July to September, as opposed to the other two crop seasons (1.42 m/s in 2018/2019 and 1.35 m/s in 2019/2020).

3.2. Oil Quality Parameters. The most important quality parameters of the oil analysis in this study are listed in Table 1. In all samples, free acidity did not exceed the limit of 0.8% established by the IOC (IOC, 2019) for the best quality olive oil, designated as extra virgin. Nevertheless, substantial variation for the percentage of oleic acid was observed for the different Zalmiti olive oil samples during the three-harvest year. The lowest acidity (0.18 ± 0.05 (% oleic acid)) was found during the 2018/2019 season for the sample with MI = 3.17, after which acidity revealed an increase during this year, attaining 0.65 ± 0.02% oleic acid at the end of maturity (MI = 4.18). Some authors have demonstrated that at the advanced stage of olive maturity, the obtained oil presents a higher percentage of free acidity due to the increase of enzymatic activity, specifically by lipolytic enzymes, favored by olive tissue damages.18

Table 1 shows that the peroxide values (PV) of the studied oils fluctuate between 7.5 and 15.56 meq O₂/kg, which are within the upper limit of the IOC norm (IP ≤ 20 meq of O₂/kg), allowing these oils to be classified under “extra virgin” category, specific to consumption. Seasonal climate fluctuations have no substantial impact on this analytical parameter. These findings on Zalmiti cultivar behavior are in agreement with those found in previous research by Saida et al.19 who studied the Chemlali cultivar and its variations as a result of climate change. Actually, the analytical parameters (FFA and PV) are not significantly influenced by the seasonal climatic variations. These findings on the “Zalmiti” cultivar behavior are similar to the previous results reported by Gutierrez et al. (1999, 2000) on Spanish cultivars (Picual and Hojiblanca). In fact, they found that FFA is a parameter negatively correlated to the temperature into an olive orchard characterized by a conventional cropping system. Indeed, FFA and PV are basically affected by several factors, including harvesting and storage of olive oil20 processing systems.21

Concerning the absorption at 232 and 270, the values vary between 1.8–2.76 and 0.06–0.17, respectively. In both cases, K₅₃₂ and K₇₅₀ were in accordance with the values recommended by the IOC which allows for their characterization as extra-virgin olive oil. With the exception of the K₅₃₂ value (2.76), which surpassed the IOC limit, during the season 2019/2020, when olive maturity was 4.7, this increment of K₅₃₂ can be related to high autumnal temperature which affects negatively the olive and caused much more oxidative reaction. However, the smallest K₇₅₀ value (0.06 for MI = 3.05) was found in oils obtained from fruits grown in dry conditions. This is the case of the 2020/2021 season where the recorded rainfall amount during autumn was very low compared to the two seasons, in
particular 2019/2020, in which the highest amount of autumnal rainfall reached 81.2 mm in October, and in this case, $K_{270} = 0.16$ for MI = 4.16. These findings agree with the results reported by the smallest $K_{270}$ value (0.06 for MI = 3.05) in oils obtained from the fruits grown in dry conditions, which is the case of the season 2020/2021, where the amount of rainfall registered during autumn is very low compared to the two seasons, in particular 2019/2020, where the high amount of autumnal rainfall of 81.2 mm was reached in October, and $K_{270} = 0.16$ for MI = 4.16. These findings concur with the outcomes given by Saida et al.\textsuperscript{19}

The olive oil color is directly associated with its carotenoid and chlorophyll contents, and it has been proposed as a quality index related to the olive variety. Table 1 demonstrates that the pigment richness of Zalmati samples varies significantly depending on the season. Nonetheless, the same pattern was seen, namely the loss of pigment during the maturation process due to degradation, followed by the formation of pheophytin a' and pyropheophytin.\textsuperscript{22} For example, during the 2018/2019 crop season, the chlorophyll pigment fell significantly during ripening, reaching 3.18 at MI = 4.18. Carotenoids follow the

![Figure 3. Sensory wheels of Zalmati virgin olive oils during three consecutive crop seasons.](http://pubs.acs.org/journal/acsodf)

Table 4. α-Tocopherols (mg/kg) of Zalmati EVOO during Three Consecutive Crop Seasons

|          | 2018/2019 | 2019/2020 | 2020/2021 |
|----------|----------|----------|----------|
| MI       | 1.12     | 2.12     | 2.85     |
| α-tocopherol | 203.52 ± 0.23 | 196.03 ± 0.41 | 202.51 ± 0.16 |
| α-tocopherol | 203.52 ± 0.23 | 196.03 ± 0.41 | 202.51 ± 0.16 |
| α-tocopherol | 203.52 ± 0.23 | 196.03 ± 0.41 | 202.51 ± 0.16 |
| α-tocopherol | 203.52 ± 0.23 | 196.03 ± 0.41 | 202.51 ± 0.16 |
| α-tocopherol | 203.52 ± 0.23 | 196.03 ± 0.41 | 202.51 ± 0.16 |
same pattern, decreasing from 7.21 to 1.13 with maturity. The change in the color of olive fruit and the decrease in the pigment content can be explained by the influence of climate conditions in addition to the influence of maturity.9 During the rainy season, the chlorophyll content increased. During the 2019/2010 and 2020/2021 seasons, oils maintained low chlorophyll contents that ranged between 10.97 and 3.97 mg/kg. However, after heavy rain during the season 2020/2021 (January, 36.59 mm and March, 31.2 mm), the chlorophyll content increased and ranged between 15.12 and 3.36 mg/kg, which is in accordance with the results described by Trabelsi et al.24 who studied the impact of drought and salinity on olive water status and physiological performance in an arid climate. Likewise, the research work of Gargouri et al.13 affirmed the influence of the growing region conditions on the amounts of chlorophylls and carotenoids. The authors have asserted that there is a significant difference between Chemlali olive oils from the south, which contained the lowest level of carotenoids, and Chemlali extracted from Hammamet (north Tunisia) which contained the highest level of carotenoids.

Given that natural phenols improve the oxidative stability, the total phenols and O-diphenols in VOO are the other important aspects to consider when evaluating their quality. The effect of the climate change on phenols and O-diphenols was readily visible due to the seasonal differences in the behavior (Table 1). The impact of climate change on phenols and O-diphenols is shown in Table 1. In these oils, the phenol content varied between 35.89 to 357.83 mg/kg. During the 2018/2019 crop season, the highest phenol and O-diphenol contents were detected in the first maturity stage (MI = 1.23) with 283.62 and 8.66 mg/kg, respectively. During the maturity progress, a decline of the total phenol content was noticed until reaching the lowest content at the end of maturity (MI = 4.18), with 43.83 and 1.62 mg/kg for total phenols and O-diphenols, respectively. Our findings corroborate those of Bengana et al.,25 who found that the phenolic compound concentrations decreased substantially during olive maturation. Furthermore, it has been known for a long time that environmental conditions can impact the content of phenolics in plant tissues. The overall phenol content of the oil was found to be related to the amount of rain that had accumulated during the year. As a result, as the weather in 2019 was characterized by low rainfall accumulation, the oil from these months for MI = 0.89 exhibited greater polyphenol contents (246.97 mg/kg), implying that water shortage creates a stress state that increases phenolic production, when compared to the lowest polyphenol concentration in olive oil (MI = 5.56) during the 2020/2021 harvest season, which was characterized by roughly 73 mm of cumulative rainfall. Therefore, the content of phenolic compounds in oils from the less rainy area is higher than that of oils from the rainier period, which is consistent with the findings of Tovar et al.26 These authors have discovered that the level of phenolic compounds in oils taken from drought-stricken crops is higher than that in oils collected from crops that have received abundant rainfall.

The other factor is temperature fluctuation, which occurs naturally during plant growth and production. Oil accumulation in olive fruits is known to begin in the second half of summer, lasting for about 8 weeks during summer and fall, and slows down during fruit ripening. In general, plants that are subjected to temperatures that are higher than their ideal growth temperature demonstrate cellular and metabolic responses that allow them to survive.27 Hence, the reproductive phase is more susceptible to high temperatures, resulting in a lower yield. Many other researchers have studied the effect of temperature on olive oil accumulation, indicating that they are negatively correlated. Figure 2 shows that the summers of the three-crop season were marked by mild temperatures, and the examined oils contain a significant amount of polyphenol. Our results are similar to those of García-Inza et al.,28 who investigated the effect of temperature on the fruit dry weight during the oil accumulation phase and discovered that average temperatures between 16 and 25 °C had no effect on the fruit dry weight, but as temperature increased, the fruit dry weight decreased.

DPPH radical scavenging is a commonly used method to estimate the ability of extracts to scavenge free radicals generated from the DPPH reagent. The DPPH radical scavenging activity of Zalmati olive oils was measured (Table 1). The lowest IC\textsubscript{50} values indicated the highest free radical scavenging activity of the sample. The IC\textsubscript{50} values of the olive oils during the three consecutive crop seasons fluctuated from 5.07 to 51.5 mg/mL. Subsequently, the lowest IC\textsubscript{50} values (5.07 mg/mL), which specified higher antioxidant potentials, were observed for the crops that had received abundant rainfall.

### Table 5. Coefficient Table of Linear Regression

| model          | unstandardized coefficients | standardized coefficients | 95.0% confidence interval for B |
|----------------|------------------------------|---------------------------|--------------------------------|
|                | B               | standard error | beta | t     | sig. | lower-bound | upper-bound |
| 1 (constant)   | −1.204          | 0.584          | −2.062 | 0.049 | −2.399 | −0.008      |
| mean temperature | 0.060          | 0.028          | 0.378 | 2.158 | 0.040 | 0.003       | 0.117      |

*Dependent variable: REGR factor score 1 for analysis 1.*
samples harvested in the last development stage of maturity (MI = 4.17). This is possibly due to the important radical inhibition caused by the high concentration of total phenols, principally oleuropein aglycone and hydroxytyrosol.29

Table 1 shows the variability between the values of oxidative stability of the studied oils. These values ranged between a maximum of 9.56 h for MI = 9.17 in the season 2020/2021 and a minimum of 3.31 h (for MI = 5.56 in the season 2020/202. The latter has the least stability, being practically unstable, which can be explained by its unsaturated fatty acid contents (53.28% of monounsaturated fatty acids and 21.46% of polyunsaturated fatty acids). Additionally, it has the modest polyphenol concentration (35.89 mg/mL), similar to the oil sample with the highest oxidative stability, which is the most stable, referring to its richness in phenols and O-diphenols of 283.62 and 8.66 mg/kg, respectively.

3.3. Fatty Acid Composition. It is due to its durability and health benefits that the interest in olive cultivars with a higher oil content and improved fatty acid composition, particularly high monounsaturated fatty acids (MUFA), has increased. This composition may differ from sample to sample, depending on the zone of production,13 the latitude,30 the climate, the variety, the stage of maturity of olives,31 and also the harvest year.32 For example, a high percentage of MUFA, mainly oleic acid, is a primordial factor determining the nutritional value of the oil as it reduces the risk of atherosclerosis and protects against different kinds of cancers.33 The fatty acid contents of Zalmati cultivar samples were evaluated in order to determine, for the first time, the effect of the climate including temperature, humidity, precipitation, and wind. Table 2 shows the average fatty acid makeup of the oil samples. It is obviously shown that the fatty acid composition of the studied oils is variable; the major fatty acids were oleic (C18:1), palmitic (C16:0), and linoleic (C18:2). The second category of acids detected in low percentages (≤4%) were stearic acid (C18:0), palmitoleic acid (C16:1), linolenic acid (C18:3), and arachidic acid (C20:0). Further, gondoic acid (C20:1), behenic acid (C22:0), lignoceric acid (C24:0), myristic acid (C14:0), margaroleic acid (C17:1), and margaric acid (C17:0) were present in trace amounts (≤0.2%) (Table 2).

During the three consecutive crop seasons, Zalmati oils possess a higher amount of palmitic acid (C16:0), with the content ranging between 17.51 and 21.82%. Besides, it has been noted that the percentages of this acid were very close to the upper limit set by IOC (20%). These values are similar to those found by Sonda et al.34 for the Zalmati variety from the same origin (Zarzis, south of Tunisia). However, no significant difference was identified between all samples for stearic acid (C18:0), a saturated fatty acid, with the amounts ranging from 2 to 3%.

As for oleic acid which is the chief fatty acid in olive oil samples, the 2019/2020 crop season contains higher levels than the two other seasons. The amount reached 62.30% in the sample with a maturity of 0.89, while during the 2018/2019 season, the percentages of oleic acid varied between 53.15 and 55.13% for MI 2.8 and 3.85, respectively. With respect to the effect of the environmental climate, the low percentages of oleic acid during the 2018/2019 season can be explained by the high temperature recorded during this year compared to the 2019/2020 season (see Supporting Information, Figure S1). This result also confirmed that in the third 2020/2021 crop season, during summer, the maximum temperature in July reached 47.14 °C, while during 2019/2020 summer, the temperature was 39.55 in the same month. The decrease in the oleic acid content in the oil extracted from olives grown at high temperatures coincides with the increase in the level of palmitic acid (C16:0) and linoleic acid (C18:2). Therefore, the highest percentages are recorded during the 2018/2019 and 2020/2021 harvest seasons, reaching 21.89% in the oil sample with the maturity index 2.89. Likewise, high levels of palmitic acid of 20.56 and 21.82% were detected during the 2018/2019 and 2020/2021 crop seasons, respectively. Our findings are in accordance with those found by Nissim et al.,35 who studied the effect of high temperature on olive oil yield and quality and
found that oil extracted from all five cultivars grown at the highest temperature site contained lower levels of oleic acid than the oil extracted from olives grown in a milder environment. In addition, the rainfall amount during the whole year influences the yield oil, on the one hand, and the composition of olive oil, on the other. It causes a slight increase in palmitic acid, oleic acid, and linoleic acid, which are in different levels in olive oils from nonrainy periods. This finding accords well with our results pertaining to the acid contents (oleic acid, palmitic acid, and linoleic acid) in olive oils during the 2020/2021 season, which is higher than those of the 2018/2019 season. Accordingly, the rainfall amount was more abundant during the 2020/2021 olive season than that recorded during the 2018/2019 season. Subsequently, the autumn rains of September—October favor the enrichment of olive oil composition, namely, oleic acid, palmitic acid, and linoleic acid. This finding is in agreement with that of Orlandi et al., who deduced that there is a direct relationship between the water stress and the levels of linoleic and linolenic acids, where a higher stress corresponds to high levels of these fatty acids.

Furthermore, the harvest year had a significant impact on all fatty acids. The interaction of both factors (harvest year × climatic conditions) was noted. As reported by the research work of Elise Sipenne et al. both the harvest year and cultivar had a significant impact on the obtained oil content from the Japanese quince seed, as well as its chemical composition. All three tested cultivars responded similar to the variable abiotic factors in different years.

The percentages of saturated, monounsaturated, and polyunsaturated fatty acids, as well as their ratios, were determined in the tested oils. It was obvious that “Zalmati” oil had a high amount of total SFAs (24.11% for Zalmati olive oil in the first maturity stage during the 2018/2019 season), essentially owing to its higher concentration of palmitic acid (20.56%), which represents the main acid of the SFA fraction. Because of its oleic content, which is variable with climatic change, Zalmati olive oil possessed an average percentage of total monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA). Citing the example of the 2019/2020 season, the oleic acid percentage was 56.92% and that of MUFA was 59.36%. These values accord well with those reported by some research works in the literature studying other olive oil varieties. The ratio of monounsaturated to polyunsaturated fatty acids (MUFA/PUFA) ranged from 2.43 to 5.17% for Zalmati olive oils (Table 4). The difference observed between samples in the fatty acid composition may be explained by the season changes. This is consistent with the findings of Osman et al., who show that the percentage of unsaturated fatty acids in olive oil increases when the temperature or altitude decreases. Other environmental variables, such as the soil properties of olive grove zones and salinity, influence the chemical composition of VOO in addition to altitude and temperature.

3.4. Triacylglycerol Composition. Acylglycerols are the chief constituents of olive oil (more than 98%), and triacylglycerols (TAGs) represent the largest part of acylglycerols. The latter is a critical characteristic in the quality of fats and oils as it can affect not only their physiological properties but also their nutritional properties such as susceptibility to lipase hydrolysis. In a previous article, the impact of the cultivar and harvest year on the triglyceride composition of olive oil for each of the three harvest years was studied, indicating a considerable cultivar on the TAG composition. The combination of cultivar and harvest year displayed a lower influence. For our study, the effect of climate changes on TAGs during three consecutive crop seasons will be considered for the samples of Zalmati olive oils. The percentage of different triglycerides is reported in Table 3.

In terms of quantitative importance, the predominance of TAGs SLO + POO fluctuating between 19.67 and 27.13% was noted. These results are comparable to those reported by Ben Mansour et al., suggesting that the triglyceride POO is very abundant in several Tunisian virgin olive oil varieties, specifically “Chemlali”. Added to this, triolein (OOO) is characterized by an abundant percentage varying from 13.18% in December 2020 to 23.21% in October 2019. Thus, PLO + SLL and LOO + PLnP have intermediate levels with values that fluctuate between 10.56 and 17.32% and 12.47 and 17.55%, respectively, followed by POP,OLL,SOO, and PLL representing a percentage that does not exceed 8%. We also detect minor TAGs, namely, OLnO, OLn, POLn, PoOP, PLP, and POS, which represent 1 and 4%. However, LLL, LOLn + POL, PLLn, and PPP are present in trace amounts (less than 1%).

The focal molecular species of TAGs in the olive oil samples are predictable from the high oleic acid and minor linoleic and linolenic acid contents. These accounted for more than 70% of the total identified TAGs, which is in agreement with the values obtained in the research work of Rigane et al. Besides, the presence of high triolein (OOO) in proportion to low trilinolein (LLL) is a favorable authenticity indicator, as defined by Ammar et al.

As for the correlation between the TAG percentages and climate, the precipitation quantity is a fundamental factor that affects the TAG composition. The 2019/2020 crop season is characterized by a considerable quantity of precipitation that attained the order of 81.2 mm during the month of October. Consequently, the percentage of triolein (OOO) reached its maximum with 23.21%, even when the 2018/2019 season rainfall was inferior in October with 22.6 mm, leading to the decrease in the percentage of triolein to 17.74%. However, for the crop season 2020/2021, no precipitation was detected during this month (0.2 mm) in which the OOO percentage was only 13.70%. Likewise, in the TAG, SLO + POO, similar behavior was perceived.

As a conclusion, the precipitation was confirmed to have a positive impact on the major TAG composition. Nonetheless, many other parameters can affect the composition and essentially the maturity of the olives, the cultivar, and the level of infestation by the olive fly.

3.5. Tocopherol Composition. Tocopherols (vitamin E) have a great importance thanks to their antioxidant properties and their beneficial biological activities. Their significance in olive oil is due to their contribution to the oxidative stability and nutritional qualities. The major compound is α-tocopherol, accounting for 98% of the full fraction. α-tocopherol of Zalmati oils is shown in Table 4, revealing that oils are rich in α-tocopherol during the three consecutive crop seasons. The crop season 2018/2019 possesses an inferior content compared to other harvest seasons. The olive sample with maturity 3.17 contains only 164.59 ± 0.3 mg/kg, similar to the sample with maturity 2.8 possessing 164.98 ± 0.94. After that, a small increase was noted in the end maturity with 164.98 ± 0.94. The season 2020/2021 had relatively high amounts of α-tocopherol. Indeed, at the first maturity stage, Zalmati oil contains a higher content of α-tocopherol (258.98 ± 0.89), which then decreases during maturity advancement until reaching 177.79 ± 0.59 mg/kg.
During the season 2019/2020, olive oil samples had various \( \alpha \)-tocopherol amounts, which are the highest amounts compared with the others, reaching 304.94 \( \pm \) 60.03 mg/kg (MI = 3.07), and the highest content was MI = 0.89 with 460.97 \( \pm \) 0.09 mg/kg (Table 4).

Dealing with climate changes, and as stated above, the content of phenols and that of \( \alpha \)-tocopherol are equally in relation with precipitation. In fact, the crop season with little precipitation quantity generates a considerable concentration of \( \alpha \)-tocopherol and vice versa.

To conclude, the tocopherol concentration in olive oils mainly depends on the environmental factors and the cultivar and olive fruit maturation.

### 3.6. Sensory Analysis

One of the most common foods in the Mediterranean region is olive oil. Over the past years, scientific knowledge pertaining to the health benefits of its frequent use has substantially enhanced the market demand all over the world. Being more valuable and expensive than any other vegetable oils, olive oil requires law protection to guarantee its quality and authenticity. European Union (EU) issued regulations that normalize both the physical and chemical characteristics of olive oil and the relevant analytical methods used to determine them. Among them, sensory evaluation (organoleptic assessment of virgin olive oil) by a trained panel entails measurements in two key areas: difference testing and descriptive analysis.

Our Zalmati samples were tested by a trained panel, whose descriptors are shown in Figure 3. Three positive descriptors, bitter, pungent, and fruity, were perceived in the studied samples, while three defect descriptors, namely racnid fusty and winey-vinegary, were observed. Along with olive oil stability, the amount of polyphenolic compounds has a significant impact on their organoleptic properties. Actually, there were significant variations in sensory attributes according to the environmental factors, cultivars, maturity index, and storage conditions that are in agreement with the findings of other studies.

As a matter of fact, during the crop season 2018/2019, no negative attributes were detected in all samples. Hence, the fruity properties reached their maximum value (5.0) in the Zalmati variety with maturity 4.18. This sample was also pungent with a value of 2, and its bitterness was 1.8. The sample with maturity 2.12 possesses a high positive intensity (fruity: 4.6, bitter: 2.7, and pungent: 3.5).

In the crop season 2019/2020, all samples possess almost equal attributes. For example, at the first maturity (MI = 0.89) stage, the Zalmati sample was characterized by the following positive attributes ((fruity: 3.7, bitter: 3.4, and pungent: 3.6). After that, a slight reduction was noticed for the sample with MI = 4.7 (fruity:3.6, bitter: 2.7, and pungent: 2.9).

In comparison with the crop season 2020/2021, all Zalmati samples revealed highly interesting sensory features, with the exception of the sample at end maturity (MI = 5.56), which had three negative attributes in addition to the favorable ones (rancid:1.5, fusty: 1.7, and winey-vinegary: 1). This result can be explained by several factors, namely the maturity of olive, storage conditions, and pedoclimatic factors.

### 3.7. Statistical Analysis

PCA was applied to the pigment contents (chlorophylls and carotenoids), maturity index, \( \alpha \)-tocopherol, \( \alpha \)-diphenol, stability, IC50, C 18:1, C 18:2, C 18:3, PUFA/SFA, MUFA/PUFA, MUFAs, and PUFAs. Three principal components (PCs) were then extracted with a Kaiser—Meyer—Olkin index >0.6 and a significant Bartlett test. The PCs explained 84.996% of the total variance of the data set. PC1 explained 44.975% of the total variance. PC1 correlated positively with the variables MUFA/PUFA (r = 0.968), MUFA (r = 0.906), C 18:1 (r = 0.962), and \( \alpha \)-tocopherol (r = 0.869) and negatively with C 18:2 (r = -0.938) and PUFA (r = -0.925). PC2 explained 20.930% of the total variance and was strongly correlated with IC 50 (r = 0.878), stability (r = -0.827), and \( \alpha \)-diphenols (r = -0.866). PC3 explained 19.091%. PC3 was associated to the pigments chlorophylls (r = 0.977) and carotenoids (r = 0.878) and correlated negatively with MI (r = -0.852) (Figure 4).

Linear regression was then used to understand the relationship between the variables correlating with the three PCs extracted from the PCA analysis and the climate data (mean temperature, wind speed, total rain, and relative humidity) obtained during the three crop seasons 2018/2019, 2019/2020, and 2020/2021 of the region of Medenin (Zarzis). Linear regression means fitting a line to the data that establishes a relationship between a target ‘y’ variable with the explanatory ‘x’ variables. In order to do a hypothesis test between ‘y’ and ‘x’, we have to assume a null hypothesis and an alternate hypothesis. The regression results showed that the R² value obtained for PC1 explaining the major part of the data’s variance and the mean temperature was 0.578. This indicates that 57.8% of the variation of MUFA, PUFAs, MUFA/PUFA, \( \alpha \)-tocopherol, C 18:1, and C 18:2 amounts was explained by the variable: mean temperature.

Table 3 (coefficient table) implies that the linear regression equation best estimates the relationship between PC1 and mean temperature. The B coefficient obtained for the mean temperature was significant (p < 0.05). Moreover, the confidence interval was 95%. Therefore, the null hypothesis was rejected, and the alternate hypothesis was accepted. The linear regression performance in the data set is shown by the linear equation below (Figure 5):

\[
PC1 = -1.202 + 0.06 \text{ mean temperature}
\]

### 4. CONCLUSIONS

The purpose of this study is to discover the short-term effects of climate change on Tunisian olive oil throughout three crop seasons. Indeed, Tunisia is a suitable case study for regional data as its climate is highly diversified with extremes ranging from Saharan climate in the south to European climate in the north. The average yearly temperature in the south is 35 °C, whereas in the north, it is 20 °C. The weather in the country’s center appears to be Mediterranean. That is why the Zalmati variety grown in the region of Medenin: Zarzis was evaluated according to its adaptation to the climate through several physicochemical methods (free fatty acids, peroxide values, UV spectrophotometry [\( K_{232} \) and \( K_{270} \)], total phenol, and \( O \)-diphenol concentrations, and sensory analysis) and by the determination of fatty acid composition, TAGs, and tocopherols.

As demonstrated by the present study, climate change had a considerable impact on olive oil samples. The preliminary findings suggested that the high autumnal temperatures have a negative impact on both fruit development and oil accumulation. These high temperatures degrade oil quality by altering its fatty acid composition, thus causing a reduction in the polyphenol and oleic acid concentrations. It is trusty to mention that no substantial differences in fatty acid and peroxide values were noticed. Seasonal climate fluctuations, particularly rainfall quantity, have a profound impact on the pigment content, which has shown a large drop during rainy seasons.
**ASSOCIATED CONTENT**

**Supporting Information**

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acsomega.2c04813.

Monthly maximum (%) temperature (°C) registered at the experimental farm during three crop seasons showing the maximum temperature of the region during the three consecutive crop seasons in which the temperature attained 45 °C during the summer period (PDF)

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**Notes**

The authors declare no competing financial interest.

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**ABBREVIATION**

VOO: virgin olive oil; FID: flame ionization detector; OS: oxidative stability; IOC: International Olive Council; ISO: International Organization for Standardization; MI: maturity index; IRA: Institute of Arid Regions

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