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EFFECT OF HARVESTING TIME ON FRUIT AND OIL CHARACTERISTICS OF SOME OLIVE CULTIVARS UNDER NORTH SINAI CONDITIONS

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ABSTRACT

The study was conducted to determine the best time for harvesting the fruits of four olive cultivars in North Sinai- Egypt, to help olive farmers obtaining the highest oil yield and quality under current climate fluctuations. This experiment involved fruit harvesting of four commercial olive cultivars (Picual, Manzanillo, Koroneiki, and Chemlali) on four different dates, (5th October, 19th October, 2nd November, and 16th November). The results showed that the maturity index (MI) varied between cultivars. Manzanillo fruits mature more than 15- 30 days earlier than other cultivars. Late harvesting dates recorded the highest maturity index compared to early harvesting dates. Oil concentration was cultivar-dependent but has been affected by climate change. The olive cultivars were arranged in descending order based on their oil content as follows: Chemlali, Koroneiki, Picual, and Manzanillo. The oil content also increased with increasing fruit maturity and then decreased significantly with increasing maturity index. Phenol, chlorophyll, and carotene content decreased as the ripening stage progressed, while the acidity and peroxide content increased. The most suitable harvesting dates were determined based on the maturity index, oil content, and total phenolic content. We recommended that the best time to harvest was 19th October for Manzanillo which can be two weeks early in hot seasons, in the second November for Picual, and Chamalali, and from 2 to 16 November for Koroneki.

INTRODUCTION

Olive trees are a common sight in the Mediterranean coast region of Egypt due to the area's mild winters, high light intensity, hot and-dry summers. According to the Ministry of Agriculture and Land Reclamation **(MALR, 2023)** report of 2023, Egypt produced approximately 1.13 million ton of olives harvested from 269 thousand Feddans during the 2021/22 season as compared to 1.08 million ton from 214 thousand Feddans in the 2017/18 season. However, despite the annual increase in olive area and production, there has been a decrease in productivity from 5.03 ton/ Feddan in 2018 to 4.19 ton/ feddan in 2022, which is a 16% reduction. This decline in productivity has also led to a decrease in the amount of olive oil produced, which fell from 40 thousand ton in 2018 to 34 thousand tons in 2021 - a decrease rate of 15% **(FAOSTAT, 2023)**. The report on the **Egypt: Virgin Olive Oil Market (2024)** confirmed this sharp decline.

Several factors affect olive tree productivity, including cultivar type, tree age, agricultural practices and climatic conditions **(Zamora *et al.*, 2001; Rondanini *et al.*, 2014)**. Thus, this decline in olive productivity and oil yield may be due to climate change, specifically heat waves and high temperatures in the Mediterranean region **(IPCC, 2012; Benlloch-González *et al.*, 2019)**.

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The amount of olive oil in fruits varies based on the cultivar type **(Samra *et al.*, 2009)**. However, oil accumulation varies within the same cultivar under different environmental conditions because oil synthesis in olive fruits follows a sigmoid-shaped curve that is closely related to climatic conditions **(Rallo and Cuevas, 2008; Rondanini *et al.*, 2011; Navas-López, 2019)**. For instance, 'Picual', 'Manzanillo', 'Koroneiki', and 'Chemlali' olive fruits were content 24-26%, 15-26%, 24-28% and 26-28% oil in fruits, respectively **(IOOC, 2000; Vossen, 2007)**. In the Mediterranean region, oil production began in August, steadily increased and reached its peak concentration in October. Afterward, the concentration stabilized until the end of the fruit ripening stage, then decreased **(García-Martos and Mancha, 1992; Sanz-Cortés *et al.*, 2002)**.

Oil accumulation began in late summer, increased from mid-September to mid-October, and slowed down in the final stages of ripening. This process was affected by an increase in average daily temperature **(Torres *et al.*, 2017)**. The ongoing climate changes during this period were harming the oil accumulation and fruit ripening process. This, in turn, leads to a reduction in fruit weight, early coloring of fruits, delayed fruit development, lower oil accumulation, and a decrease in oil quality. This decrease in quality was due to a reduction in polyphenols, amino acid synthesis, enzyme activity in cell walls, vitamin E activity, and antioxidant compounds **(Torres *et al.*, 2017; García-Inza *et al.*, 2018)**. Thus, farmers may need to adjust their harvest time to maintain production levels. If fruits are harvested early, the oil may have a higher percentage of polyphenols and tocopherols, resulting in good-quality oil. However, sometimes the oil may not taste good. On the other hand, if the fruits were harvested late, there may be an increase in the rate of fruit drop and a decrease in oil quality, but the quantity of oil crops was higher **(Haggag *et al.*, 2013)**.

Hence, it was crucial to determine the optimal harvesting time to balance olive oil quality and productivity for a good economic return from the olive grove. From this point, this study has aimed to investigate the most suitable harvesting date for four olive cultivars in the North Sinai region to achieve the highest oil yield and quality under now climate fluctuations.

MATERIALS AND METHODS

The present study was conducted on four olive cultivars namely: Picual, Manzanillo, Koroneiki, and Chemlali grown at the experimental station, Faculty of Environmental Agricultural Sciences (31°07'38"N, 33°49'30"E, 15 m sea level altitude), Arish University, North Sinai, Egypt. Twenty mature olive trees from each cultivar about 30 years old, similar in vigor and size, and planted at 5 × 5 m apart on sandy loam soil (Table 1). The trees received the same annual horticultural care and depended on drip irrigation (Artesian water well; Table 2). The manual harvest was done every two weeks from early October to mid-November on four different harvesting dates (5^{th} October, 19^{th} October, 2^{nd} November, and 16^{th} November) during experimental seasons 2021, 2022 and 2023. The trees were arranged in a randomized complete block design (RCBD) with three replicates (3 trees/replicate) per experimental unit.

Temperature figures are based on data from the Central Climate Laboratory (CLAC), Egypt, and Visual Crossing Corporation Limited Weather Service (www.visualcrossing.com), in the years 2018, 2021, 2022, and 2023 (Fig. 1). Between August and November 2021, the average temperature was 25.3°C. There were some heat waves during this period, with the highest temperature reaching 40.4°C, while the minimum temperature was 10.4°C. However, in 2022 and 2023, the average temperature during the same period increased

Table 1. Physical and chemical properties of the olive orchard soil

Physical properties				Chemical properties									
						Cations (meq.l^{-1})				Anions (meq.l^{-1})			
Sand (%)	**Silt (%)**	**Clay (%)**	**Soil texture**	**EC (dS.m^{-1})**	**pH**	**Ca^{++}**	**Mg^{++}**	**Na^{+}**	**K^{+}**	**CO_3^{-}**	**HCO_3^{-}**	**Cl^{-}**	**SO_4^{-}**
83.55	13.20	3.25	Sandy loam	1.31	8.5	4.23	8.23	3.80	1.32	-	4.50	5.75	7.33

- Soils, Water & Environment Res. Ins., Agric. Res. Center, Ismailia, Egypt.

Table 2. Chemical analysis of artesian water well used for irrigation

EC (dS.m^{-1})	Cations (meq.l^{-1})				Anions (meq.l^{-1})				S.A.R
	Ca^{++}	**Mg^{++}**	**Na^{+}**	**K^{+}**	**CO_3^{-}**	**HCO_3^{-}**	**Cl^{-}**	**SO_4^{-}**	
6.60	20.80	16.00	19.20	0.30	-	2.5	43.0	10.8	10.07

- Soils, Water & Environment Res. Ins., Agric. Res. Center, Ismailia, Egypt.

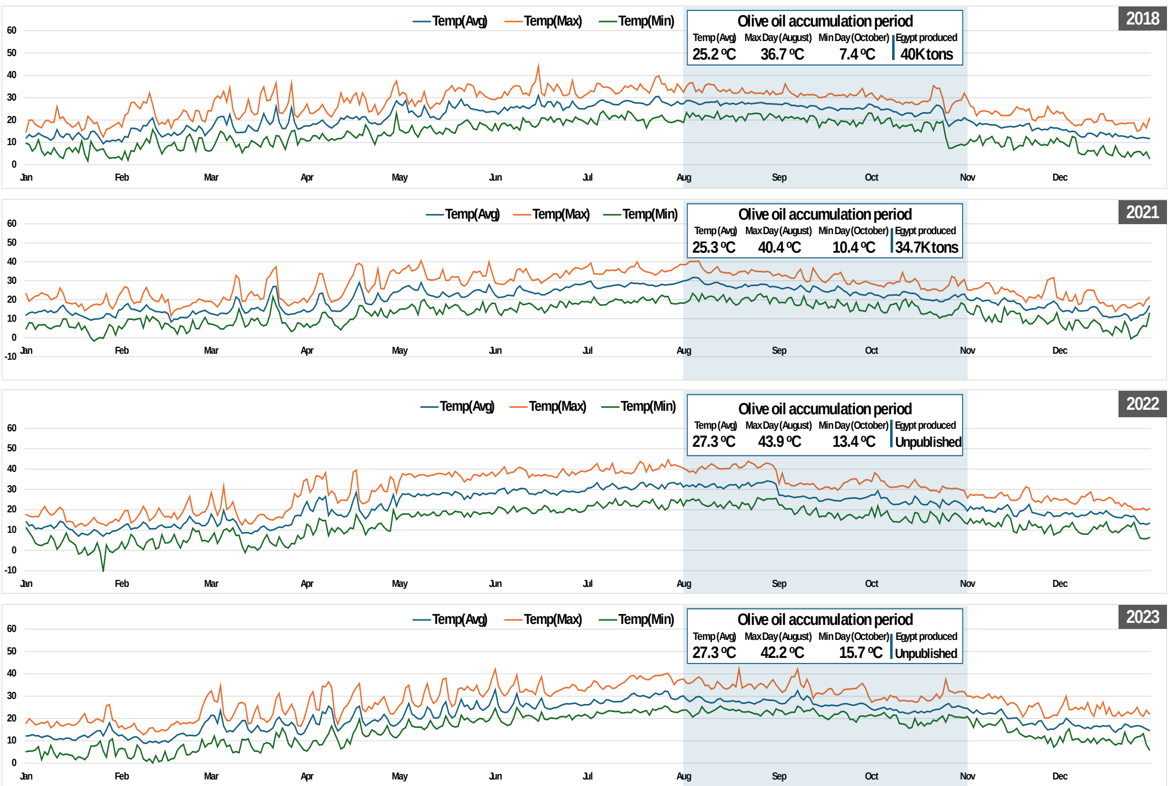

Fig. 1. Temperature (°C) for 2018 (As the highest year for olive oil production) and three experimental seasons 2021, 2022, and 2023 in El-Arish, North Sinai, Egypt. The light blue box corresponds to the accumulation of the olive oil period, referring to the relation between the temperature average in this period and olive oil production (North Sinai was used as an indication of the general situation occurring in Egypt).

by two degrees Celsius. The maximum temperature in 2022 was 43.9°C, and in 2023, it was 42.2°C. It is worth noting that there has been a noticeable increase in air temperatures overall, or an increase in the number of heat waves, compared to 2018.

Fruit Physical Characteristics

One hundred healthy olive fruits were randomly selected in each experimental unit from tree circumference. The fruits were weighed and used to determine maturity index (MI) according to **Boskou (1996)**. Fruit length and width were measured *via* digital Caliper. The weight of the fruit flesh and seed was recorded using a digital balance and subsequently, the flesh/pit ratio was calculated using the equation [Flesh/pit ratio=fresh flesh weight - fresh pit weight]. Also, approximately 10 g of fruit flesh was dried at 75°C for 48 hours to calculate the moisture content (%).

Oil Extraction and Percentage Estimation

The obtained dried samples were then ground using a small mill and transferred after wrapping 1 g into filter paper with thread to the Soxhlet extraction apparatus to determine the oil content (% of fresh and dry weights) using petroleum ether (100 ml at 60°C for 8 hours) according to **AOAC (2000)**. Also, about 500 g of whole olive fruit was crushed using a metal hand grinder then the paste was centrifuged at 7000 rpm for 10 minutes. Oils were collected by pipette, transferred into dark bottles, and stored at 5°C for further oil chemical analyses.

Olive Oil Characteristics

Using the International Olive Council for sensory analyses of olive oils **(IOOC, 2017)**, oil acidity was determined by titrating method with 0.1 N NaOH and expressed as oleic acid (%), and peroxide value was analyzed by titrated sample with 0.02 N thiosulfate solution (expressed as meqO^2/kg oil). The UV light absorption traits (K232 and K270) were estimated in a solution with an oil sample and cyclohexane (1:5 W:V) and absorbance was recorded at 232 and 270 nm.

Subsequently, total chlorophyll and carotenoid compounds were estimated using cyclohexane at absorbance 670 and 470 nm, respectively, according to **Minguez-Mosquera *et al.*, (1991)** method. To measure the total phenol content; the Folin–Ciocalteu reagent at 765 nm wavelength was used according to **Montedoro *et al.* (1992)**.

Statistical Analysis

Results data were statistically analyzed by the two-factor analysis of variance (ANOVA) using Co-STAT® software. The differences between means were determined using Duncan's test at a 5% probability level **(Duncan, 1955)**.

RESULTS

Olive Fruit Physical Characteristics

Results indicate that there were highly significant differences between the harvesting dates and olive cultivars on fruit maturity index, fruit weight, fruit length, fruit width, flesh/pit ratio, and moisture content in the three successive seasons 2021, 2022, and 2023 (Table 3).

The maturity index is a color indicator that often indicates the maturity of fruits and the optimal harvest time **(Lavee, 1996)**. The four olive cultivars showed significant differences in fruit skin color between each of the different harvest dates. Results indicated that the skin and flesh of Manzanillo tend to turn black and purple earlier than Picual, Koroneiki, and Chemlali cultivars in the three seasons. The cultivar Manzanillo on 19th October had an optimum maturity index of 4.69, 4.34, and 4.90 in 2021, 2022, and 2023, respectively which is in line with the international standard for maturity index

Table 3. Effect of harvest date on fruit maturity and physical traits of the four olive cultivars

Maturity index

Treatment	2021				2022				2023			
	5 Oct.	19 Oct.	2 Nov.	16 Nov.	5 Oct.	19 Oct.	2 Nov.	16 Nov.	5 Oct.	19 Oct.	2 Nov.	16 Nov.
Picual	1.92 ij	2.18 h	3.43 f	5.02 c	1.94 jk	2.11 i	3.20 g	4.94 b	1.93 l	2.24 j	5.74 b	5.74 b
Manzanillo	3.70 e	4.69 d	5.37 b	5.74 a	3.52 e	4.34 c	5.36 a	5.42 a	3.88 g	4.90 d	5.48 c	6.50 a
Koroneiki	1.02 l	1.73 k	2.78 g	3.70 e	1.09 m	1.71 l	2.58 h	3.53 e	1.15 n	1.76 m	3.03 i	4.00 f
Chemlali	1.87 j	2.04 i	3.42 f	4.64 d	1.87 k	2.03 ij	3.32 f	4.18 d	1.88 l	2.09 k	3.55 h	4.68 e
Average	2.13 D	2.66 C	3.75 B	4.78 A	2.10 D	2.54 C	3.61 B	4.52 A	2.21 D	2.75 C	4.45 B	5.23 A

Fruit weight (g)

Treatments	2021				2022				2023			
	5 Oct.	19 Oct.	2 Nov.	16 Nov.	5 Oct.	19 Oct.	2 Nov.	16 Nov.	5 Oct.	19 Oct.	2 Nov.	16 Nov.
Picual	3.74 g	4.08 f	5.69 d	6.11 c	3.87 h	4.99 f	6.01 d	6.30 c	3.16 h	4.54 e	5.74 c	6.00 b
Manzanillo	5.37 e	5.80 d	6.71 a	6.46 b	5.56 e	5.91 d	6.98 a	6.70 b	4.86 d	5.86 bc	6.24 a	5.87 bc
Koroneiki	0.90 k	1.34 j	1.42 ij	1.55 i	0.87 l	1.51 k	1.55 jk	1.70 j	0.75 k	1.41 j	1.44 j	1.57 j
Chemlali	2.12 h	3.74 g	4.07 f	4.17 f	2.27 i	3.81 h	3.99 h	4.26 g	2.06 i	3.56 g	3.78 f	3.91 f
Average	3.03 C	3.74 B	4.47 A	4.57 A	3.14 D	4.05 C	4.63 B	4.74 A	2.70 C	3.84 B	4.30 A	4.34 A

Fruit length (mm)

Treatments	2021				2022				2023			
	5 Oct.	19 Oct.	2 Nov.	16 Nov.	5 Oct.	19 Oct.	2 Nov.	16 Nov.	5 Oct.	19 Oct.	2 Nov.	16 Nov.
Picual	22.89 h	23.39fg	23.05gh	23.94de	23.51 e	23.76de	23.05 f	23.93cd	21.08 g	21.56 f	22.70 c	23.60 a
Manzanillo	24.42bc	25.30 a	24.79 b	24.68bc	24.12 cd	25.28 a	24.80 b	24.68 b	21.7 ef	22.05d	23.05 b	22.12 d
Koroneiki	16.12 l	16.23 l	17.92 k	18.69 j	17.31 k	17.85 j	18.65 i	19.38 h	15.32 k	16.28 j	16.81 i	16.86 i
Chemlali	20.32 i	23.75ef	24.30cd	24.72 b	21.22 g	24.30 c	24.86 b	25.01ab	19.78 h	21.09 g	21.67 f	22.52 c
Average	20.94D	22.17 C	22.48 B	23.03 A	21.54 C	22.80 B	22.84 B	23.25 A	19.48 D	20.24C	21.06B	21.27A

Fruit width (mm)

Treatments	2021				2022				2023			
	5 Oct.	19 Oct.	2 Nov.	16 Nov.	5 Oct.	19 Oct.	2 Nov.	16 Nov.	5 Oct.	19 Oct.	2 Nov.	16 Nov.
Picual	20.81 b	21.18 b	21.20 b	21.68 a	21.74 cd	22.15bc	22.91 a	22.38 b	19.42 c	19.79bc	22.34 a	22.56 a
Manzanillo	19.72 c	19.88 c	21.10 b	21.17 b	20.12 f	21.15 e	21.50 de	20.22 f	17.01 e	17.79 d	19.84 b	18.10 d
Koroneiki	11.13 g	11.26 g	12.45 f	12.46 f	11.30 j	11.32 j	12.83 i	12.86 i	10.62 k	10.61 k	11.65 j	12.19 i
Chemlali	14.98 e	16.26 d	16.33 d	16.45 d	15.52 h	16.54 g	16.68 g	16.82 g	13.72 h	15.54 g	15.18 g	16.41 f
Average	16.66C	17.14 B	17.77 A	17.94 A	17.17 D	17.79 C	18.48 A	18.07 B	17.31 A	17.25A	15.93B	15.19C

Flesh/pit ratio

Treatments	2021				2022				2023			
	5 Oct.	19 Oct.	2 Nov.	16 Nov.	5 Oct.	19 Oct.	2 Nov.	16 Nov.	5 Oct.	19 Oct.	2 Nov.	16 Nov.
Picual	3.83 f	4.55 e	5.46 d	5.96 c	4.03 d	5.34 c	6.04 b	6.42 ab	3.84 e	4.19 d	5.37 b	5.66 a
Manzanillo	6.32 ab	6.14 bc	6.40 a	6.13 bc	6.38 ab	6.53 a	6.52 a	6.09 b	4.32 d	5.18 bc	5.84 a	5.09 c
Koroneiki	3.09 h	3.27 gh	3.36 g	3.48 g	3.55 ef	3.57 ef	3.70def	3.84 de	2.92 i	3.04 hi	3.02 hi	3.16 gh
Chemlali	1.94 i	3.34 g	3.44 g	4.05 f	2.18 g	3.31 f	3.39 f	4.05 d	1.92 j	3.31 fg	3.37 f	3.80 e
Average	3.80 D	4.32 C	4.67 B	4.90 A	4.03 D	4.69 C	4.91 B	5.10 A	3.25 C	3.93 B	4.40 A	4.43 A

Moisture content (%)

Treatments	2021				2022				2023			
	5 Oct.	19 Oct.	2 Nov.	16 Nov.	5 Oct.	19 Oct.	2 Nov.	16 Nov.	5 Oct.	19 Oct.	2 Nov.	16 Nov.
Picual	69.64 a	62.42 b	56.89 e	47.99 h	71.44 a	63.57 b	59.92 de	56.71 g	66.64 a	60.87 b	53.04 d	42.04 h
Manzanillo	69.20 a	61.36bc	54.19 f	45.74 i	72.78 a	62.14bc	54.88 h	50.13 i	67.99 a	59.31 c	49.05 f	43.02gh
Koroneiki	60.30cd	53.02 f	47.72 h	42.32 j	63.97 b	57.62 fg	53.75 h	48.70 i	58.00 c	49.13 f	43.92 g	39.62 i
Chemlali	59.67 d	56.94 e	50.48 g	48.69 h	61.66 cd	60.98cd	58.98 ef	50.52 i	51.11 e	50.66 e	43.33gh	38.57 i
Average	64.70 A	58.43 B	52.32 C	46.19 D	67.46 A	61.08 B	56.88 C	51.51 D	60.93 A	54.99 B	47.33 C	40.81 D

for olive fruit. On the last harvest date (16th November), the Picual, Koroneiki, and Chemlali cultivars achieved the maximum maturity index of 5.02, 3.70, and 4.64, respectively in 2021, 4.94, 3.53 and 4.18, respectively in 2022, and 5.74, 4.00, and 4.68, respectively in 2023. Regarding fruit mass, the maximum fruit weight was recorded in the fruits harvested at the late harvest date (2nd November and 16th November). The Koroneiki produced lighter fruits than the Manzanillo which produced the bigger fruits. The highest weight was shown in the fruits harvested on the third harvest date (2nd November) in the cv. Manzanillo with 6.71 g, 6.98 g, and 6.24 g in the three seasons, respectively. Olive cv. On the same trend, Manzanillo fruit on the 19th October 2021, and 2022 seasons was statistically ($P \leq 0.05$) taller than the other three olive cultivars. But on 2nd November, Picual outperformed the Manzanillo, Koroneiki, and Chemlali cultivars by recording the highest fruit length under high-temperature conditions in 2023. The cv. Picual superiority continued by recording the widest fruit with a value of 21.68 mm on 16th November 2021, as well as 22.91 and 22.34 mm on 2nd November 2022, and 2023, respectively. Whereas Koroneiki presented lower significant length and width values than the other cultivars.

Moreover, by comparing the four olive cultivars it was found that the flesh/pit ratio increases with the maturation time. The late harvest date (16th November) recorded the highest flesh/pit ratio compared with the early harvest date (5th October) which recorded the lowest ratio in the three seasons. Olive cv. Manzanillo gave higher values of flesh/pit ratio with 6.25%, 6.38%, and 5.11% in 2021, 2022, and 2023 respectively, but Koroneiki and Chemlali cultivars gave the lowest ratio between fruit flesh to pit. In general, the cv. Manzanillo fruits harvested on 2nd November recorded the highest flesh/pit ratio in the three seasons. The highest percentage between flesh and pit weight was recorded for the Koroneiki and Chemlali cultivars at the late harvest date (16th November).

Fruit moisture content (%) was also significantly influenced by the harvesting dates. The moisture content of the fruits reached 64.70%, 67.46%, and 60.39% on 5th October in the 2021, 2022, and 2023 seasons. While the fruits harvested on 16th November declined a lot in moisture content to 46.19%, 51.51%, and 40.81% in the three seasons. There was a significant difference in moisture content between the early harvest date and the late harvest in the three seasons. Manzanillo and Picual cultivars achieved the highest moisture content rather to the Koroneiki, and Chemlali cultivars, especially at the earlier harvesting dates. Manzanillo, Picual, Koroneiki, and Chemlali cultivars lost about 31.08%, 33.90%, 29.81%, and 18.40%, respectively in the 2021 season and 20.61%, 31.12%, 23.87, and 18.06%, respectively in the 2022 season. These rates increased to 36.91%, 36.72%, 31.68%, and 24.53%, respectively in the 2023 season.

Olive Oil Characteristics

Oil percentage increased directly with fruit maturity (Fig. 2). In 2021, the oil percentage was raised from 38.84% to 42.05% for Picual, from 37.59% to 45.40% for Koroneiki, and from 38.40% to 49.16% for Chemlali. In 2022, the oil % was raised from 38.80% to 47.33% for Picual, from 36.80% to 48.74% for Koroneiki, and from 42.55% to 49.40% for Chemlali.

In 2023, the Picual raised from 30.26% to 33.39%, Koroneiki from 31.36 to 37.05, and Chemlali from 39.84% to 42.78%. Conversely, the same Figure showed that the fruit oil content of Manzanillo slightly increased from the 5th to the 19th of October and then had an overall downward trend across the period from the 19th of October up to the 16th of November. Also, it can be

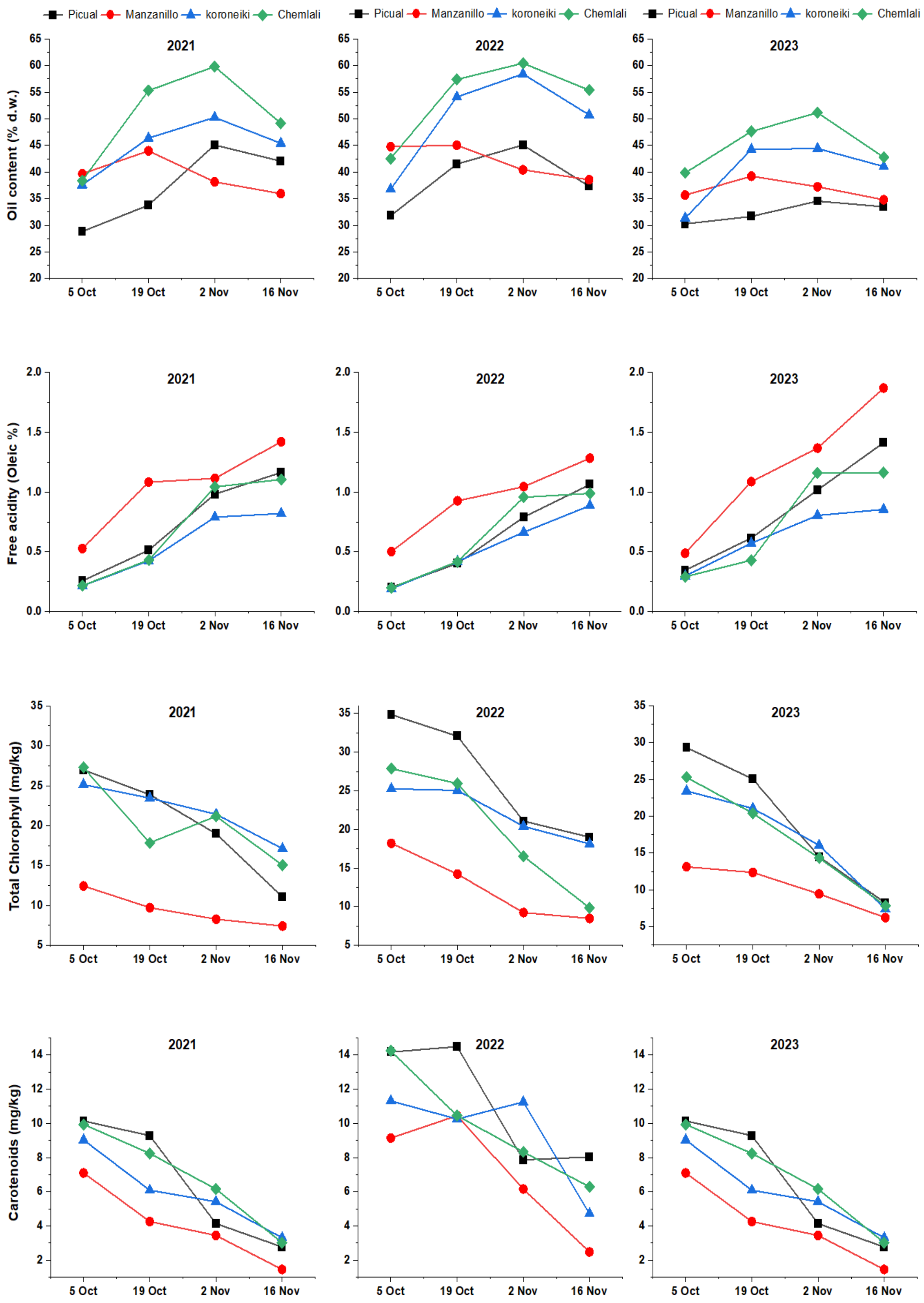

Fig. 2. Oil content, free acidity, total chlorophyll, and carotenoids of four olive cultivars at different harvesting dates

noticed that the oil content in the fruit decreased sharply from the 2021 to 2023 seasons at the different harvesting dates. These maximums were reached in 2022, then in 2021 and the lowest oil content was recorded in 2023 of all studied olive cultivars.

Furthermore, a significant difference ($P \leq 0.05$) in oil-free acidity (Oleic %) was found between the four studied olive cultivars in the three experimental seasons. The lowest acidity (0.258, 0.204, and 0.346% in Picual, 0.216, 0.192, and 0.298% in Koroneiki, and 0.218, 0.200 and 0.292% in Chemlali cultivar) recorded on 5th October harvest date in 2021, 2022, and 2023 seasons, respectively. However, during subsequent harvests, all the studied olive cultivars experienced a considerable increase in oil-free acidity. On the last harvest date (16th November), the free acidity on cv. Picual reached 1.163, 1.062, and 1.412%, cv. Koroneiki with 0.820, 0.886, and 1.868%, and cv. Chemlali with 1.104, 0.988, and 1.162% in the first, second, and third seasons, respectively. Meanwhile, delaying the harvest of Manzanillo fruits from 5th October to 16th November led to record a maximum free acidity percentage of 1.420% in 2021, 1.282% in 2022, and 1.868% in 2023.

As the fruit ripening process progressed, there was a significant decrease in oil pigment contents, as illustrated in Figure 2. Fruits harvested early (5th October) contained high chlorophyll and carotenoid concentrations compared with the last harvested date (16th November). On 5th October, the highest chlorophyll contents (26.97 and 27.28 mg/kg) were recorded with Picual and Chemlali cultivars, respectively in the 2021 season, 34.86 mg/kg with cv. Picual in the 2022 season, and 29.33 mg/kg with cv. Picual in the 2023 season. Moreover, the Chemlali cultivar showed higher carotenoid content with a maximum of 12.53, 14.23, and 9.94 mg/kg followed by the Picual cultivar with 12.06, 14.17, and 10.14 mg/kg on 5th October 2021, 2022, and 2023. Overall, on the last harvest date (16th Nov.), the cultivar Manzanillo recorded a minimum oil pigment content (chlorophyll and carotenoid) in three experimental seasons.

Moreover, it can be noticed that the peroxide value of oil fruit varied among the experimental seasons (Fig. 3). The same tendency was observed with K232 and K270 values. The lowest values were recorded in the 2022 season, followed by the 2021 season while the highest values were in the 2023 season, affected by high temperatures during the period of oil accumulation. The peroxide value increased rapidly during ripening, and K232 and K270 followed a similar trend to that of peroxide value but the percent rise was lower. There was also a significant difference between olive fruits that were harvested early and late. The peroxide value, K232, and K270 increased progressively from 5th October (early harvest date) to 16th November (late harvest date). Manzanillo had the highest peroxide values, K232, and K270 followed by cv. Picual, while the least effective were Koroneiki and Chemlali cultivars.

However, along the progression of the maturity period, the phenol content differs according to olive cultivars which ranges from the very high levels (554.40, 605.80, and 484.78 mg/kg) found in Chemlali and (502.68, 555.72, and 454.78 mg/kg) in Koroneiki to the very low levels (347.39, 358.59 and 361.83 mg/kg) found in Manzanillo and (486.41, 515.41 and 428.63 mg/kg) in Picual through three experimental seasons, respectively. Also, during fruit ripening, the phenols accumulated in the fruit reached a maximum value of 698.46 mg/kg with Koroneiki on 19th October 2021, 705.80 and 692.14 mg/kg with Chemlali on the 5th and 19th of October 2022, respectively, and 621.73 and 590.80 mg/ kg with Chemlali on 5th and 19th of

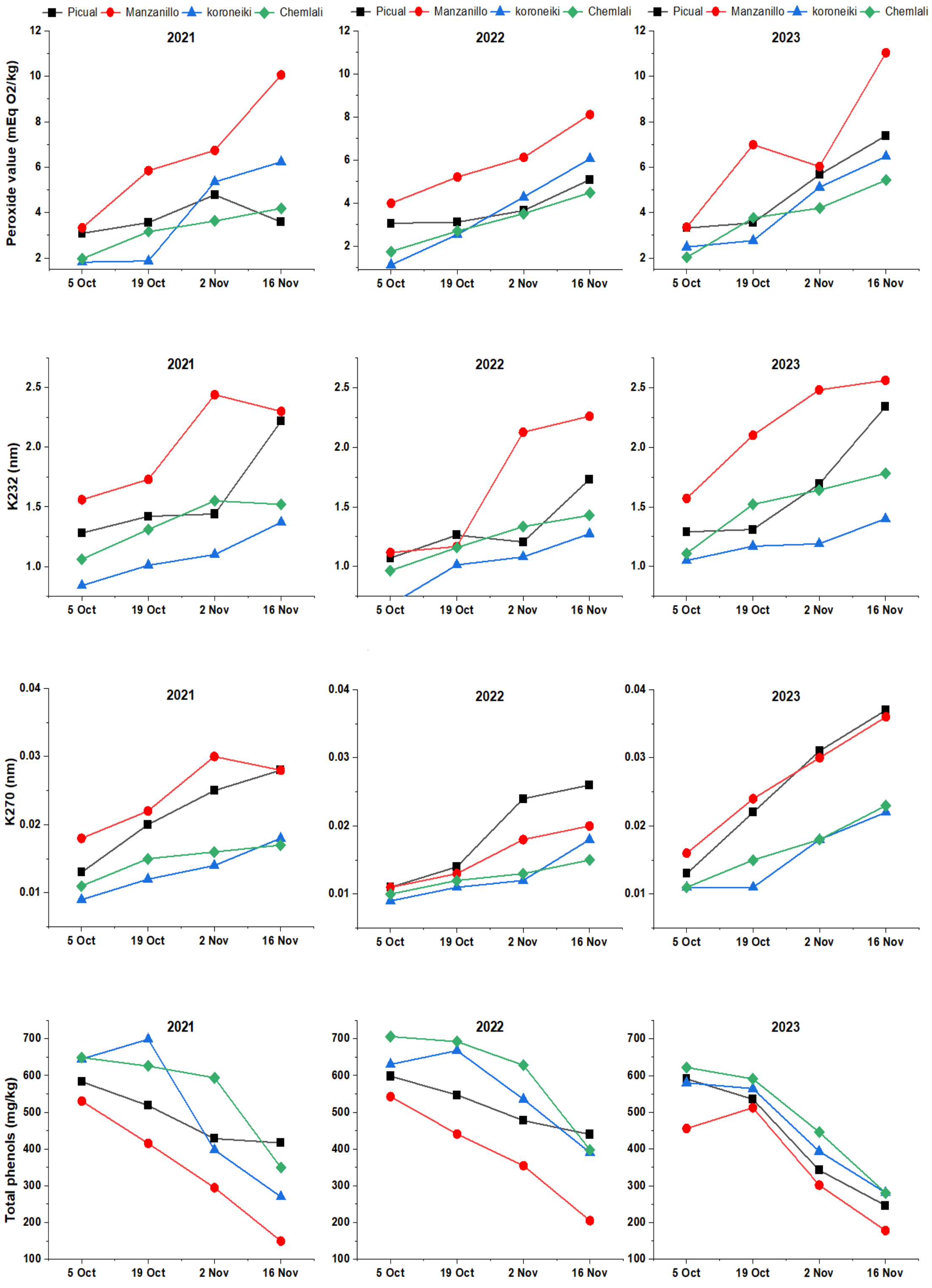

Fig. 3. Peroxide value, K232, K270 and total phenols of four olive cultivars at different harvesting dates

October 2023, respectively. While cv. Manzanillo gave the lowest phenol content (149.55, 204.89, and 177.94 mg/kg) in the 2021, 2022, and 2023 seasons.

Determination of Optimum Harvesting Dates

The optimal date to harvest olives under North Sinai climate conditions of Picual, Manzanillo, Koroneiki, and Chemlali cultivars was determined based on important ripening indexes. These indexes include the maturity index, oil content, and total phenolic content for the 2021, 2022, and 2023 seasons **(**according to **Mahhou *et al.*, 2012)**. The ideal time to harvest olives is when the maturity index intersects with the highest levels of oil and satisfactory concentration of the phenol curve (as shown in Fig. 4).

For Picual cultivar, the best time to harvest was on 2nd November, with a maturity index between 3.43, 3.20, and 5.74 in the three seasons, respectively. For Manzanillo cultivar, the optimal time to harvest was on 19th October, with a maturity index between 4.69 and 4.90 in the 2021 and 2022 seasons, respectively, and on 5th October with a maturity index of 4.34 in the 2023 season. For Koroneiki cultivar, the best time to harvest is on 19th October, with a maturity index of 2.78 in 2021, while it was preferred from the period of 19th October to 2nd November with a maturity index of 2.58 and 3.03. Lastly, for Chemlali cultivar, the ideal time to harvest was on 2nd November, with a maturity index between 3.42, 3.32, and 3.55 in the three seasons, respectively.

DISCUSSION

The general physico-chemical analyses as well as the maturity index vary strongly between the Manzanillo Picual, Koroneiki, and Chemlali cultivars. This variation is due to the differences in their genetic makeup and the interaction of gene expression with environmental conditions. This phenomenon is similar to what was observed in the studies conducted by **Abdalla *et al.* (2008)** and **Bakshi *et al.* (2018)**. **Ali *et al.* (2022**) observed that Manzanillo ranked first in all categories, including fruit weight, flesh percentage, fruit moisture percentage, and oil percentage of the dry fruit weight, followed by Picual and Koroneiki cultivars. On the same line, **Fouad *et al.* (1992), EL-Said *et al.* (2006)** and **Samra *et al.* (2009)** stated that the Koroneiki cultivar produced a higher oil content compared to Picual, however, Picual gave higher fruit weight, length, width, and soluble solids with lower acidity than Koroneiki. Also, the total phenolic content was higher than Picual and Manzanillo cultivars, which is consistent with **Vossen (2005)**. Meanwhile, Manzanillo fruits in this study matured earlier than other cultivars. It is possible due to the earlier flowering date of the Manzanillo cultivar. This can be explained by **Ali *et al.* (2022**) who clarified that the Manzanillo cultivar flowers and fruit sets earlier than the Picual and Koroneiki cultivars by approximately two weeks. There were no significant differences in the flowering time between the Picual and Koroneiki cultivars.

On the other hand, results indicated that harvesting dates have a significant effect on the physical and chemical properties. All previous studies have confirmed that various metrics of the fruit change significantly as it ripens, including the maturity index, fruit weight, length, width, flesh/pit ratio, oil content, and oil quality composition **(Montedoro *et al.* 1986; Yousfi *et al.* 2006; Abdalla *et al.* 2008; Bakshi *et al.* 2018**). This is due to the fruit following the Sigmund growth curve, as explained by **Rallo and Cuevas (2008)** and **Rondanini *et al.* (2011)**. During the ripening process, physiochemical changes occur naturally, but increased rates may be due to temperature effects, either direct or indirect. Late harvesting of olive crops and high

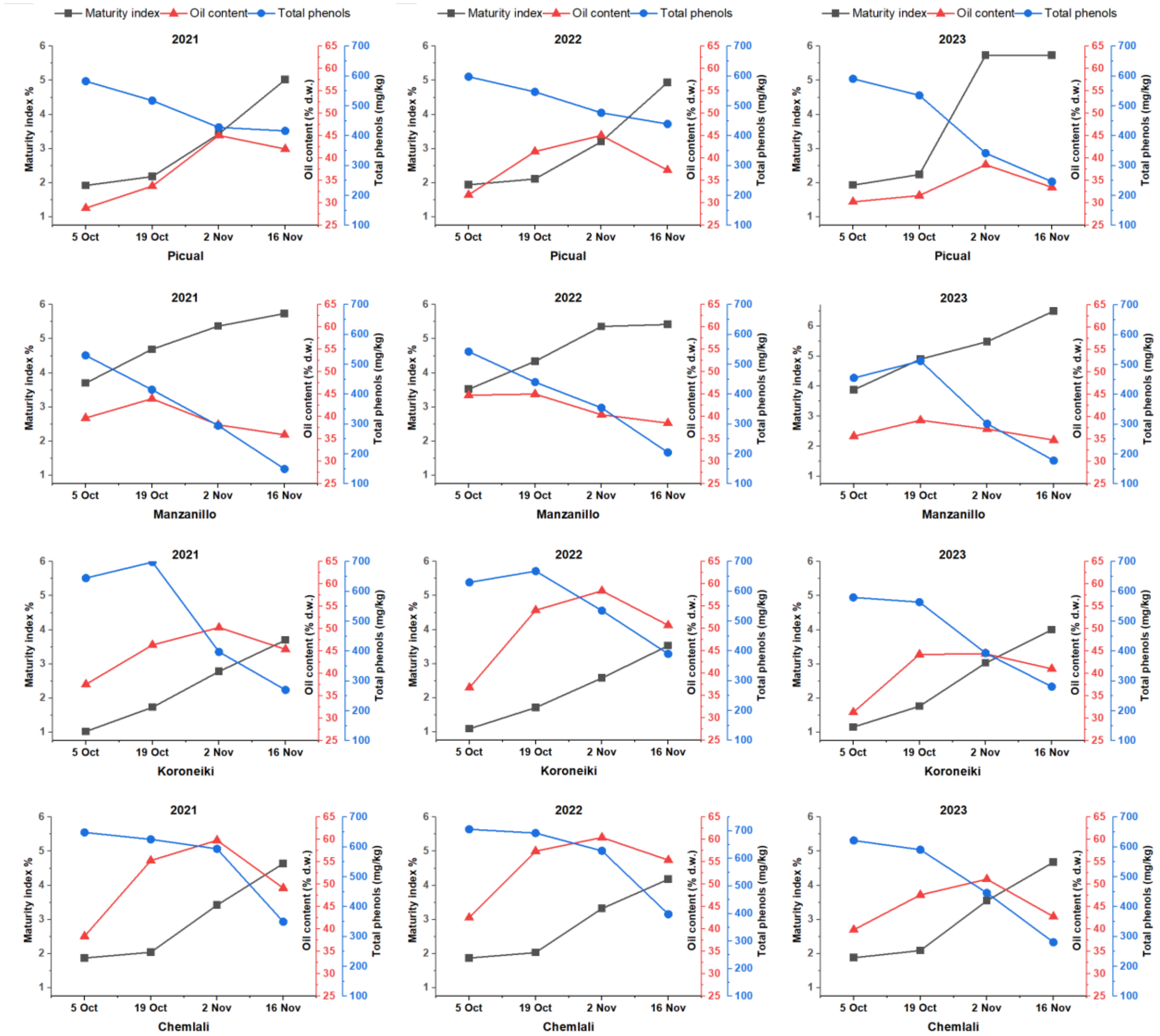

Fig. 4. Optimum harvest dates for Manzanillo, Picual, Koroneiki, and Chemlali cultivars based on the maturity index, oil content, and total phenol content under North Sinai climate conditions in the 2021, 2022, and 2023 seasons.

temperatures during processing can increase the levels of free fatty acids in the oil due to the activation of lipase enzymes and hydrolysis **(Lawson 1995; Ryan *et al.* 1998; Anastasopoulos *et al.* 2011**).

Furthermore, the decrease in phenolic content during fruit maturation was shown between the four studied olive cultivars. The presence of polyphenols in the oil enhances its resistance to oxidation **(Gutierrez Rosales *et al.* 1992)**. A study by **Salvador *et al.* (2001), Amiot *et al.* (1989)** and **Paz Romero *et al.* (2003)** showed that the levels of total polyphenols decrease as the olive fruit ripens due to the degradation of oleuropein, the main phenolic compound. And the temperature factors may play a key role in this reaction **(Skevin *et al.* 2003)**. In addition, Chlorophyll affects oil stability, and its green color is associated with freshness by consumers **(Ryan *et al.* 1998)**. Results showed that chlorophylls and carotenoids were degraded, and anthocyanins were synthesized during the maturation of olive fruits, which is consistent with the study of **Hörtensteiner (2006)**. Normally, this is due to the activation of degrading enzymes as maturity progresses **(Al-Maaitah *et al.* 2009)**. But the warmer conditions can increase this activity **(Lípová *et al.* 2010)**.

The peroxide value is a key method for oil quality evaluation, reflecting its oxidation rate. The results showed that the peroxide value dramatically decreased from 5th October to 16th November. Also, the results showed a similar pattern between peroxide values and both K232 and K270. A study has confirmed that the peroxide value of oil increases with harvesting time, as observed by **Freihat *et al.* (2008)** and **Ibrahim (2016)**. This could be due to Lipoxygenase enzyme activity increasing peroxide values in oil, causing the formation of hydroperoxide that leads to rancid odors and flavors. Higher air temperatures stimulate this reaction. Hydroperoxides decompose aldehydes and ketones, which are detailed in K232 and K270 **(Lawson, 1995; Koprivnjak and Conte, 1998)**.

This explains why some researchers do not recommend harvesting olive fruits in the early stage of growth and development. Because the amount of oil produced is very small, and the sensory characteristics are unacceptable **(Gandul-Rojas *et al.*, 1996; Mailer *et al.*, 2002)**. As the fruits continue to develop, oil starts accumulating, and the fruit's moisture content, chlorophyll, carotene, polyphenol, and antioxidants increase while peroxide values, K232, and K270 remain low **(Criado *et al.*, 2007; Abdalla *et al.*, 2008)**. This is the ideal time to harvest olives to obtain the highest quality oil, but not for maximum oil concentration. However, the oil concentration increases over time, and this is considered the best time to harvest olives for maximum oil yields. This increase in oil content may be due to the increased biosynthesis of triacylglycerols, which reach 99% of oil until full maturity **(Harwood *et al.*, 2000; Bakshi *et al.*, 2018)**. During this time, the chemical oil properties such as chlorophyll, carotene, polyphenols, antioxidants, and triacylglycerols gradually decrease. In contrast, the acidity, peroxide value, K232, and K270 increase dramatically. These findings are consistent with those of **(Gandul-Rojas *et al.*, 1996; Garcia *et al.*, 1996)**.

This study also showed that oil content and oil quality vary more from year to year. Fruits and oil properties were changed rapidly during the fruit growth stage. The same investigation was observed by **(Mailer *et al.*, 2005; Nissim *et al.*, 2020)**. This suggests that high air temperatures can directly impact the accumulation of oil and the ripening of fruit, which are crucial stages for olive fruit growth **(Tombesi, 1994; Rallo and Cuevas, 2008; Rondanini *et al.*, 2011; Navas-López, 2019)**. Given that this period falls from August to late October, which is when climate changes are most severe (as depicted in Fig. 1), it is especially critical under North Sinai conditions.

In 2021, North Sinai faced heat waves with a maximum temperature of 40.40^{o}C, affecting the ripening process of Manzanillo fruit. The fruit turned purple-black earlier than usual due to increased anthocyanin pigment accumulation. Optimum maturity was reached earlier than the common harvest season in North Sinai, resulting in smaller fruits with higher oil quality on 5th October. However, the fruit's weight and dimensions increased significantly by 19th October, along with increased oil accumulation. The negative trend continued until the last date of harvest, resulting in decreased oil quality traits and a lower oil percentage. Additionally, heat waves affected the Picual cultivar. Delaying harvest date resulted in high fruit weight, but low oil percentage and total phenolic content. Chemlali and Koroneiki cultivars were highly tolerant to high-temperature conditions and recorded the lowest rate of fruit moisture loss and the highest rate of increasing oil between different harvest dates. Late harvest was considered the optimal date for these cultivars, resulting in maximum oil percentage with low acidity and high content of chlorophyll, carotene, and phenolic compounds.

In 2022, climate data indicated that the average temperature increased by about 2°C during the oil accumulation period. Despite this, there has been a slight improvement in the oil characteristics in terms of quantity and quality compared to the previous year. The fruits ripened earlier and the oil content was increased. The same pattern was observed by **Ortega-Nieto (1969)**. The best harvest date for the cv. Manzanillo was October 20, while for Picual, Koroneiki, and Chemlali cultivars, it was 16^{th} November to obtain the highest weight and physical characteristics. The best time to harvest for obtaining the highest oil percentage, chlorophyll, carotene, phenolic compounds, and the lowest oil acidity was observed to be the first of November.

In the year 2023, the weather conditions were almost identical to those of the previous year, 2022. This similarity in weather may explain the same tendency observed in physical and chemical parameters. Due to the high temperature, the fruits have ripened earlier than expected. Based on the maturity index, the Manzanillo fruits can be harvested in the first week of October, while the Picual, Koroneiki, and Chemlali fruits can be harvested in the first week of November. However, to obtain a higher percentage of oil and larger fruits, it is recommended to delay the harvest of Manzanillo fruits by two weeks. However, doing so resulted in a significantly lower quality of olive oil.

These results are consistent with **Nissim *et al.* (2020)** who found that when the temperature during the oil accumulation period reached 46°C in 2016 and 45°C in 2017, the olive fruits ripened earlier as well as the fruit weight, oil concentration, and oil quality also significantly decreased. The effect was greater in 2016 than in 2017. Moreover, a temperature rise of 4°C above the normal temperature for the region each year can have several negative effects on olive crops. It can cause a delay in fruit maturation, which in turn can reduce the oil content due to a delay in lipogenesis. It can also result in smaller fruit size and ultimately lead to a reduction in yield **(Benlloch-González *et al.* 2019)**. Other findings **Garcı´a-Inza *et al.* (2014)** also found that in the olive cultivar 'Arauco' when the temperature increased above 25˚C, the fruit dry weight decreased by about 0.08 grams and oil concentration at 1.1% per each additional 1˚C. Also, the fruit oil yield was decreased under a temperature range of 23°-27°C compared with cooler regions in Argentina **(Rondanini *et al.* 2011 and Rondanini *et al.* 2014)**. On the same line, **Trentacoste *et al.* (2012)** observed a decrease in fruit weight and oil concentration in ten olive varieties, including Picual and Manzanillo, as the maximum daily temperature increased. Accordingly, it is important to decide to harvest when striking a balance between the quantity and quality of oil during harvesting.

Conclusions

The results presented in this work showed that olive fruit ripening rate and oil quality are directly affected by increasing air temperature. If the average temperature goes beyond 25^{o}C or the heat waves surpass 40^{o}C for several consecutive days during the olive oil accumulation period, it will undoubtedly harm the weight of the fruit, and the oil quantity and quality. This can be prevented if early harvesting at a lower maturity index of the olive fruits is considered. For Manzanillo, the best time was 19^{th} October, which can be two weeks early in hot seasons, on 2nd November for Picual, and Chamalali, and from 2^{nd} to 16^{th} November for Koroneki.

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الملخص العربي

تأثير وقت الحصاد على خصائص الثمار والزيت لبعض أصناف الزيتون تحت ظروف شمال سيناء

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أجريت هذه الدراسة لتحديد أفضل وقت لحصاد ثمار أربعة أصناف من الزيتون في شمال سيناء-مصر، لمساعدة مزارعي الزيتون في الحصول على أعلى إنتاجية وجودة لزيت الزيتون في ظل التقلبات المناخية الحالية. وقد تم حصاد ثمار أربعة أصناف زيتون تجارية (بيكوال، مانزانيللو، كروناكي وشملالي) في أربعة مواعيد مختلفة (5 أكتوبر، 19 أكتوبر، 2 نوفمبر و 16 نوفمبر). أظهرت النتائج أن هناك اختلاف في مؤشر النضج بين الأصناف المدروسة، حيث نضجت ثمار المنزانيللو قبل الأصناف الأخرى بحوالي 15-30 يومًا. كما سجلت مواعيد الحصاد المتأخرة أعلى مؤشر نضج مقارنة بالحصاد المبكر. اعتمد تركيز الزيت في الثمار على الصنف ولكنه تأثر بتغير المناخ. تم ترتيب أصناف الزيتون تنازليًا حسب محتواها من الزيت على النحو التالي: الشملالي، الكروناكي، البيكوال، المنزانيللو. ولوحظ ازدياد محتوى الزيت مع زيادة نضج الثمار ثم انخفاضه بشكل معنوي بزيادة مؤشر نضج الثمار. كما انخفض محتوى الفينول الكلي والكلوروفيل والكاروتين في الزيت مع تقدم مرحلة النضج، بينما زاد محتوى الحموضة ورقم البيروكسيد. تم تحديد مواعيد الحصاد الأكثر ملائمة على أساس مؤشر النضج، ومحتوى الزيت ومحتوى الفينول الكلي. ونوصي بأن أفضل وقت للحصاد هو 19 أكتوبر لصنف المنزانيللو، والذي يمكن تبكيره إسبوعين في المواسم الحارة، وكانت في 2 نوفمبر بالنسبة لصنف البيكوال والشملالي، ومن 2 إلى 16 نوفمبر بالنسبة لصنف الكروناكي.

الكلمات الإسترشادية: الزيتون، جودة الزيت، موعد الحصاد، التغير المناخي.

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