Factors that Affect the Quality of Olive Oil Produced Using Olives from Traditional Orchards in the Middle East

Arnon Dag[1], Isaac Zipori[1], and Zipora Tietel[1]

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Abstract. **Traditional olive (*Olea europaea*) orchards have been grown for thousands of years and still occupy most of the world's cultivated olive areas. To compete with olive oil produced in the higher-yielding intensive orchards, the oil from traditional orchards must be of high quality. We evaluated oil quality—potential and actual (under commercial conditions)—and tested the stages in the production chain that are likely to reduce oil quality in the traditional sector in the Middle East region. Our findings show a clear negative impact of growers' traditional practices on both the chemical and sensory characteristics of olive oil. The oil originating from the commercial process had higher free fatty acid and lower polyphenol and carotenoid contents, lower stability, lower pungency, lower fruitiness, lower bitterness, and a higher prevalence of organoleptic defects than oil that originated from fruit picked from the same trees during the experimental procedure. The current common harvesting technique of pole beating significantly increased fruit injury and fruit with mold, leading to a reduction in oil polyphenols and an increase in free fatty acid levels compared with those resulting from manual picking. In addition, after harvest, storing the fruit for more than 48 hours in plastic bags dramatically reduced the oil quality. The traditional olive orchard could be a source of high-quality extra virgin olive oil. However, fruit handling—from the trees until the end of the oil extraction process—is performed incorrectly, thus adversely affecting the oil quality.**

Olive (*Olea europaea*) oil, which is recognized for its nutritional (Jimenez-Lopez et al. 2020), sensory (Fernandes et al. 2018), and medicinal attributes (Jiménez-Sánchez et al. 2022), has a unique place in culinary (Dancausa-Millán et al. 2022) and Mediterranean landscapes (Dancausa Millán et al. 2023). For centuries, olive cultivation has been intertwined with human history and has played a pivotal role in various cultures and civilizations (El-Kholy et al. 2012). Traditional olive production accounts for a large proportion of olive orchards, particularly in marginal areas. In general, the traditional system can be described as a low-intensity farming system (Beaufoy et al. 1994). It is associated with old trees grown at low density without irrigation, low yields, low agrochemical inputs, and a low degree of mechanization (Duarte et al. 2008). Olive harvesting in traditional olive orchards is mainly performed by manual methods involving long poles or sticks (Sola-Guirado et al. 2014), and extended delays between harvest and milling are common (Vossen 2007).

The Middle East region plays a special role in olive cultivation. Domestication and cultivation of olives started in this region 6500 years ago, earlier than that in any other place in the world (Barazani et al. 2023; Galili et al. 1997; Langgut and Garfinkel 2022; Langgut et al. 2019). Hence, this area has the longest tradition of olive cultivation.

The traditional rain-fed olive orchards in the Middle East grow Souri as the predominant cultivar (Barazani et al. 2014; Lavee et al. 2008). These orchards are not adapted for mechanical harvesting, and manual harvesting leads to increased labor costs. In addition, the productivity of these orchards is relatively low compared with that of intensive ones, and their low profitability is raising concerns about their future (Lavee 2009). One of the solutions proposed in Europe for the traditional orchards with low profitability was to brand these oils under the Protected Designation of Origin (PDO) system, which allows the growers to receive higher prices for their virgin olive oil (VOO) (Ballco and Gracia 2020). However, branding under PDO requires the production of extra virgin olive oil (EVOO). Therefore, we assessed the major quality parameters of VOO produced in traditional orchards and the possible causes of its deterioration. Specifically, we explored the potential of the traditionally grown olive to produce high-quality oil and assessed the overall effects of the growers' practices, harvesting methods, and fruit storage from harvest to mill on the oil's quality.

Materials and methods

Three aspects were studied during the current study: the effect of general orchard management; the effect of the harvesting method; and the effect of fruit storage practices.

Orchard locations

Eleven representative, typical, traditional rain-fed olive orchards of different ages in the northern part of Israel were selected in Summer 2021. In each orchard, six bearing trees (replicates) with medium to high fruit loads were selected. The geographical distribution of the different orchard locations is presented in Fig. 1.

Orchard characteristics are presented in Table 1. The southernmost orchards were at a low altitude of 60 to 180 meters above sea level (m.a.s.l.), and the altitude increased with the northward progression of the orchard locations. In all 11 selected traditional rain-fed olive orchards, the soil is stony and calcareous, with a medium to heavy texture. The climate is typical Mediterranean with a cool, rainy winter and a dry, hot summer. In all orchards, the cultivar was Souri.

Fruit sampling

Effect of commercial practices on oil quality. A few days before the commercial harvest, between mid-October and mid-November, a 2-kg sample of olives was hand-picked from

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[1]Gilat Research Center, Agricultural Research Organization, Volcani Institute, 852800, Israel

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A.D. and Z.T. contributed equally to this work.

A.D. is the corresponding author. E-mail: arnondag@agri.gov.il.

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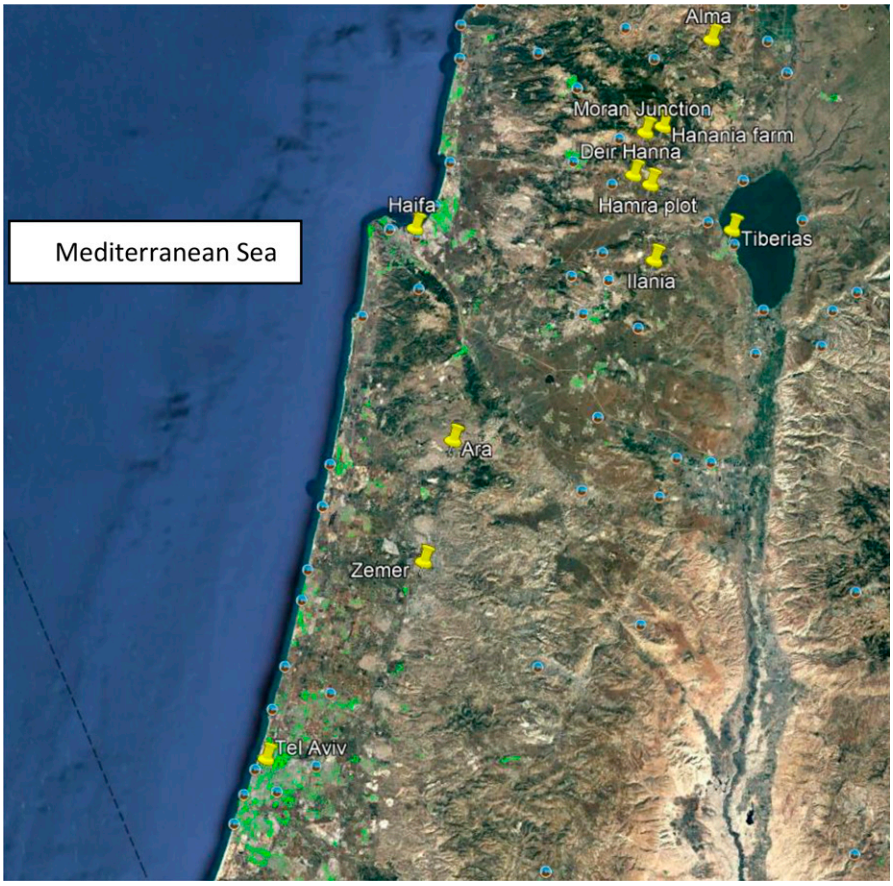

Fig. 1. Geographical distribution of the sampled Souri olive orchards in northern Israel included in the different experiments.

each selected tree in each orchard. Each sample was treated separately regarding oil extraction and chemical analysis. For the sensory analysis, the oil extracted from all six trees was pooled together to obtain sufficient oil for the sensory panel.

Effect of the harvest method. In 4 of the 11 selected orchards, simultaneous with the grower's harvest, three harvest methods were tested using four trees (replicates): manual picking; the traditional harvest method, i.e., beating the canopy with a pole to detach the fruit and collecting them on nets extended on the ground; and the use of electric combs (Pellenc, Pertuis, France) to detach the fruit and collect them on nets extended on the ground. In each orchard, a 2-kg subsample of olives was taken from each tree and for each harvest method, reaching a total of 12 samples per orchard. All three harvest methods were tested using the same tree. First, a 2-kg representative sample was hand-picked. Then, the pole-beating method was applied for some branches until enough fruits were available for the 2-kg sample required. Finally, the electric comb was used to obtain another 2-kg sample of olives from other branches.

Effect of fruit storage. In two of the aforementioned four orchards, two types of storage, ventilated 20-kg boxes and nonventilated 20-kg plastic bags (similar to the practice of some growers), were tested during the commercial harvest. Three storage times, 24, 48, and 120 h, were tested. Each combination of storage method and storage duration had four replicates.

Fruit characterization

The following fruit parameters of a subsample of 100 fruit were measured: rotten (moldy) fruit index and injury index. Both indexes were measured using a scale of 0 to 10, with 0 indicating no rot or injury and 10 indicating heavy rot or injury. Rotting and injury intensities were estimated

Table 1. Locations and characteristics of the sampled Souri olive orchards in northern Israel used for the different experiments. Orchards are ranked from south (lat. 32°22′18.35″N, long. 35°02′17.29″E) to north (lat. 33°04′36.78″N, long. 35°30′49.97″E).

Orchard location	Grower code[i]	Altitude (m)[ii]	Orchard age (yr)	Tree distancing (m)	Avg annual precipitation (mm)[iii]
Zemer	G3	60	80	10*10	595
Ara 1	G1	180	15	7*6	620
Ara 2	G2	1808	>100	10*12	620
Ilania	G4	300	90	8*9	500
Deir-Hanna 1	G6	300	8	6*6	616
Deir-Hanna 2	G7	300	70	10*10	616
Deir-Hanna 3	G8	300	18	4*7	616
Eilaboun Junction	G9	200	120	10*10	550
Moran Junction 1	G11	500	>100	8*10	700
Moran Junction 2	G11	500	>100	10*10	700
Hanania farm	G10	900	>100	6*10	737
Alma	G5	600	>100	10*10	688

[i] In the first experiment ("effect of current commercial process on oil quality"), all the orchards were included and the data regarding the oil quality of samples from the two locations of G11 were merged, In the second experiment ("effect of harvest methods on oil quality"), four orchards were included (G2, G5, G1O, and G7). In the third experiment ("effect of fruit storage on oil quality"), fruits from one orchard (G9) were examined.
[ii] 1 m = 3.2808 ft.
[iii] 1 mm = 0.0394 inch.

for each of the 100 fruits in the subsample, and the number of fruits from a given category was multiplied by the intensity level, resulting in the rotting/injury intensity; this value was divided by 100. The minimum possible value of this parameter was zero, and the maximum possible value was 10.

Laboratory and commercial oil extraction and oil content determination

Commercial oil extraction was performed at three-phase medium-scale olive mills. The olives from each orchard were processed at a nearby mill selected by the grower; it was usually the geographically nearest one to the orchard. Laboratory oil extraction of all olive samples was conducted using a laboratory-scale olive mill (Abencor; mc2 Ingenieria y Sistemas, Seville, Spain). After extraction, the oil was filtered using filtering paper. A subsample from the olive paste was taken to determine oil and water contents using a calibrated near-infrared (NIR) spectrometer (OliveScan; Foss, Hilleroed, Denmark) (Zipori et al. 2016).

Oil chemical analysis

An olive oil sample representing commercial harvesting and oil extraction processes was taken from the olive mill at each orchard. This sample was filtered and analyzed with the olive oil samples obtained from the laboratory extraction. A chemical analysis was performed as described previously (Tietel et al. 2019).

Free fatty acid (FFA) levels were determined using the International Organization for Standardization (ISO) analytical method 660. The FFA level was expressed as the percent of oleic acid. Phenolic compounds were isolated from a solution of oil in hexane by double-extraction with methanol–water (60:40 volume/volume). The peroxide value (ISO 3960), expressed as the milliequivalent of active oxygen per kilogram (mEq/kg) of oil, was determined using the following method: a mixture of oil and iso-octane:acetic acid 3:2 was allowed to react in darkness with a potassium iodide solution; then, the free iodine was titrated with a sodium thiosulfate solution.

The polyphenol content, expressed as tyrosol equivalents (mg/kg of oil), was determined with an ultraviolet-visible spectrophotometer (Beckman Coulter, Fullerton, CA, USA) at a wavelength of 735 nm using Folin–Ciocalteu reagent (Swain and Hillis 1959). The fatty acid composition was determined by gas chromatography using a gas chromatograph equipped with a mass spectrometer (6850 N; Agilent Technologies, Santa Clara, CA, USA) and DB23 capillary column (length, 60 m; diameter, 0.25 mm; thickness, 0.25 μm; DB23; J&W Scientific, Folsom, CA, USA) following cold methylation according to International Olive Council (IOC) method COI/T.20/Doc. No. 24, 2001. Helium was used as the carrier gas (Maxima, Ashdod, Israel). The detector temperature was set to 250 °C. The oven temperature was maintained at 175 °C for 5 min; then, it was increased at 5 °C·min^{-1} to 240 °C and maintained for 7 min until the end of the 25-min run. The injection volume was 1 μL (Commission Regulation 2568/91, corresponding to American Oil Chemists' Society method Ch2-91). Fatty acids were identified by comparing the retention time with standard compounds (FAME Mix C8–C24; Supelco, Bellefonte, PA, USA). The relative composition of fatty acids in the olive oil was determined as the percentage of total fatty acids.

The total carotenoid content was measured according to the method described by Salvador et al. (2001) and modified for a 96-well plate: 420 μL oil was mixed with 980 μL isooctane to obtain 30% oil in isooctane, and 200 μL was pipetted into a 96-well plate and read at 470 nm in four replicates. Path-length correction and specific extinction values were used. A sterol analysis was modified for a 96-well plate (Araújo et al. 2013). A 100-μL aliquot of oil was mixed with 900 μL chloroform, and 300 μL was pipetted out and mixed with 200 μL chloroform; 200 μL of this solution was pipetted into a 96-well plate, which was kept in the dark for 15 min and then read at 625 nm. A tocopherol analysis was modified for a 96-well plate from (Wong et al. 1988). A 40-μL aliquot of oil was weighed, and 1 mL toluene was added and mixed well; 700 μL 2,2′-bipyridine (0.07% weight/volume in 95% aqueous ethanol) and 100 μL ferric chloride hexahydrate (0.2% weight/volume in 95% aqueous ethanol) were added (in that order). The solution was increased to 2 mL with 95% aqueous ethanol. After standing for 1 min, absorbance at 520 nm was determined using a blank solution as a reference that was prepared as described but without the oil. Solutions were protected from strong light during color development. The method was calibrated by preparing standards containing 0 to 240 μg of pure α-tocopherol in 10 mL of toluene and then performing the analysis as described.

Oil sensory analysis

A sensory assessment was performed by an IOC-recognized panel (Israel's Southern Panel) following the IOC COI/T.20/Doc. No 15/Rev method regulation.

Data analysis

Data were analyzed using statistical software (JMP version 16; SAS Institute Inc., Cary, NC, USA) and one-way analysis of variance. Significant differences were determined by Student's paired t test at $P \leq 0.05$.

Results

Effect of current commercial processes on oil quality. During this study, we assessed the effect of the current commercial processes used by the growers in the oil production chain [including harvest, fruit storage until milling (time and storage conditions and milling), and oil extraction] and compared them to the experimental laboratory-scale processes. The experimental process aimed to minimize oil deterioration, thus reflecting the quality potential of the oil when the harvesting and milling are performed properly. Our results are based on 11 orchards (four trees in each one) that were harvested manually (for a total of 44 samples). The quality of the oil from those samples was compared with the quality of the oil from olives harvested from the same plot using the commercial process.

The oil content in the paste, based on the dry weight of the sampled fruit in most orchards, reached the maximum possible content of 50% (Zipori et al. 2016) or was very close to this value at the time of the experimental harvest.

The average FFA content in the oil obtained in the sampled orchards is presented in Table 2. For all orchards, the FFA values of the experimental sample were lower than those of the oil obtained from the commercial harvest and oil extraction. The

Table 2. Olive oil free fatty acid content, polyphenols, stability, peroxide value, carotenoids, chlorophyll, tocopherols, and phytosterols in oils that originated from commercial and experimental harvesting at 11 traditional orchards.

Treatment	Free fatty acids (% oleic)	Polyphenols ($mg \cdot kg^{-1}$)[i]	Stability (h)	Peroxide value (O_2) (mEq/kg)[ii]	Carotenoids ($mg \cdot kg^{-1}$)	Chlorophyll ($mg \cdot kg^{-1}$)	Tocopherols ($mg \cdot g^{-1}$)	Phytosterols ($mg \cdot g^{-1}$)
Commercial	1.03	333.4	26.16	10.52	3.68	11.08	3.01	10.52
Experimental	0.46	696.9	49.91	9.74	6.68	14.83	2.62	9.74
Significant	*	*	*	NS	*	*	NS	NS

[i] 1 mg·kg = 1 ppm.
[ii] 1 O_2 (mEq/kg) = 1 $mmol \cdot kg^{-1}$.
* Significant difference ($P < 0.05$).
NS = no significant difference ($P > 0.05$).

experimental harvest of all of the samples was less than 0.8%, the threshold for EVOO; however, in the commercial harvest, most of the samples (6 of 11) were above this threshold and did not meet the standard for EVOO.

The polyphenol content in the oil obtained from the sampled orchards is presented in Table 2. In all 11 orchards, the oil polyphenol content in the experimentally harvested fruit was higher than that in the oil from the commercially harvested fruit. The average polyphenol content in the experimentally harvested orchard was double the level of that in the commercially harvested orchard (333.4 vs. 696.9 $mg \cdot kg^{-1}$, respectively). Similarly, the oil stability of oil that originated from olives that were experimentally harvested and processed was double that of oil that originated from olives that were commercially harvested (49.91 vs. 26.16 h, respectively) (Table 2). The oil's secondary metabolites content is presented in Table 2. Whereas the contents of carotenoids and chlorophyll were significantly higher in the oil that originated from experimentally harvested fruit, the contents of tocopherols and phytosterols were unaffected by the harvesting method. Similarly, the peroxide value was unaffected by the treatments.

There was a significant difference in the fatty acid profiles of the oil obtained from the commercial process and that obtained by the experimental process (Table 3). The commercial practice led to significant elevations in oleic acid, margaric acid, and the ratio of monounsaturated to polyunsaturated fatty acids, and a significant reduction in palmitoleic acid, linoleic acid, linolenic acid, and the ratio of saturated to unsaturated fatty acids.

The average fruitiness level in the experimentally harvested fruit was 3.5, whereas that in the commercially harvested fruit was only 1.6. The average olive oil bitterness in the experimentally harvested fruit was 3.8, and that of the commercially harvested fruit was 2.4. Oil pungency, which was 4.2 in the experimentally harvested fruit, was only 2.6 in the commercially harvested fruit. In the experimental harvest, 3 of the 10 oils contained defects, and the defect level was relatively low (<2); however, in the commercial harvest, 9 of the 10 oils contained defects, and their levels were high (range, 2–4). Hence, the experimental harvest resulted in better positive attributes and less negative attributes (defects) than the commercial harvest (Table 4)

Effect of the harvest method. In this experiment, we aimed to isolate the harvesting stage from the commercial oil production chain to understand its role in oil quality degradation. We used a subset of four orchards/replications with four-tree subsets; each was harvested using three different methods, for a total of four replications of three methods 12 samples per orchard, and a total of 48 samples. The manual harvest represents the least disruptive harvesting method and was used during the first experiment ("experimental" harvesting). Pole beating is the commercial method used by the farmers, and the electric comb is a more modern method of fruit harvesting that reduces labor costs.

The fruits that were harvested by pole beating were significantly more injured than the manually harvested fruit (74.5% vs. 38.6%, respectively), whereas electric comb harvesting resulted in an intermediate value of 58.3% injured fruit (Fig. 2A). The incidence of fruit mold of when the pole beating and electric comb harvesting methods were used was more than double that observed with the manual method (Fig. 2B). The FFA levels were significantly higher in the oil originating from fruit harvested using pole beating (0.49%) than in oil originating from fruit that was manually harvested (0.38%); electric comb harvesting resulted in an intermediate value of 0.42% (Fig. 2C). All treatments met the EVOO standard. Commercial harvesting (pole beating) also caused a reduction in polyphenols in the oil [from 648.8 $mg \cdot kg^{-1}$ (manual harvesting) to 482.3 $mg \cdot kg^{-1}$]. Electric comb harvesting resulted in an intermediate level of 549.4 $mg \cdot kg^{-1}$.

The harvesting method barely affected the contents of secondary metabolites in the oils (Fig. 3). Carotenoids, tocopherols, and phytosterols were not significantly affected by the harvesting

Table 3. Olive oil fatty acid profile, ratio of monounsaturated to polyunsaturated fatty acids (MUFA/PUFA), and ratio of saturated to unsaturated fatty acids (SFA/UFA) in oils that originated from commercial and experimental harvesting at 11 traditional orchards.

Harvest	Palmitic acid (%)	Stearic acid (%)	Palmitoleic acid (%)	Oleic acid (%)	Linoleic acid (%)	Linolenic acid (%)	Arachidic acid (%)	Margaric acid (%)	MUFA/PUFA	SFA/UFA
	C16:0	C18:0	C16:1	C18:1	C18:2	C18:3	C20:0	C17:0		
Commercial	11.8	3.6	0.7	71.1	10.0	0.4	0.5	0.6	7.1	0.21
Experimental	14.4	3.7	1.0	65.9	11.7	0.7	0.9	0.4	5.6	0.25
Significance	*[i]	NS	*	*	*	*	NS	*	*	*

[i] Significant difference between oil originating from commercial harvesting and experimental harvesting ($P < 0.05$).
NS = no significant difference ($P > 0.05$).

Table 4. Intensity of the positive and negative attributes of the sensory assessment of olive oils that originated from commercial and experimental harvesting at 11 traditional orchards (using a scale of 0–10 according to the IOC COI/T.20/ Doc. No 15/Rev method regulation).

Attribute	Grower	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11
	Harvest											
Fruitiness	Exp.	5	3.5	3.5	3.5	4	3	3	3.3	4	2.3	2.8
	Com.	2.3	2	2	2	4	0	2	2	0	0	ND
Bitterness	Exp.	4.5	4	3	4	4	4	4	3	4	4	4
	Com.	2.5	2.5	2	2	3	2.5	2.5	2.5	2.5	2	ND
Pungency	Exp.	4.5	5	3.8	4	4	4	5	4	4	4	4
	Com.	3	3.5	2	2	4	2	3	3	1.5	2	ND
Defects[i]	Exp.	0	0	0	0	0	1.8	1	0	0	0.5	0
	Com.	2.3	3.5	2	3	0	4	4	4	3.5	3.8	ND

[i] The main defect detected by the sensory panel was "fusty."
Com. = commercial harvesting; Exp. = experimental harvesting; ND = no data.

methods; however, the chlorophyll content was significantly higher in oils obtained from fruit harvested using the electric comb (Fig. 3C).

Effect of fruit storage. Mold was more prevalent in fruit stored in plastic bags (Fig. 4A). The FFA levels in the extracted oil slightly increased for 48 h; then, they increased sharply toward 120 h of storage of the fruits. This deterioration process was faster for fruit stored in bags than for fruit stored in ventilated boxes (Fig. 4B). Polyphenols in the extracted oil decreased gradually, with no difference between fruit storage methods (Fig. 4C), and similar trends were observed for oil stability (Fig. 4D).

Total carotenoids in the oil decreased slightly with the length of fruit storage, with this reduction being more pronounced for bagged fruit (Fig. 5A). The negative impact of storage in bags compared with that in boxes was highly pronounced for tocopherol, which decreased to one-third of its initial level and was significantly lower than that of fruit stored for 120 h (Fig. 5B). Phytosterols increased during fruit storage, with slightly higher values observed with bags (Fig. 5C). Chlorophyll levels in the oil also increased slightly with fruit storage, with no difference between bags and boxes (Fig. 5D).

Discussion

Various factors contribute to the reduction of VOO quality in the production chain, such as orchard management (e.g., high irrigation levels) (Bustan et al. 2014; Dag et al. 2015), overfertilization with nitrogen (Erel et al. 2013), harvesting time, which might harm the fruit and reduce oil quality (Dag et al. 2008), the time elapsed between harvesting and milling (Dag et al. 2012), and the oil extraction method (Ben-David et al. 2010).

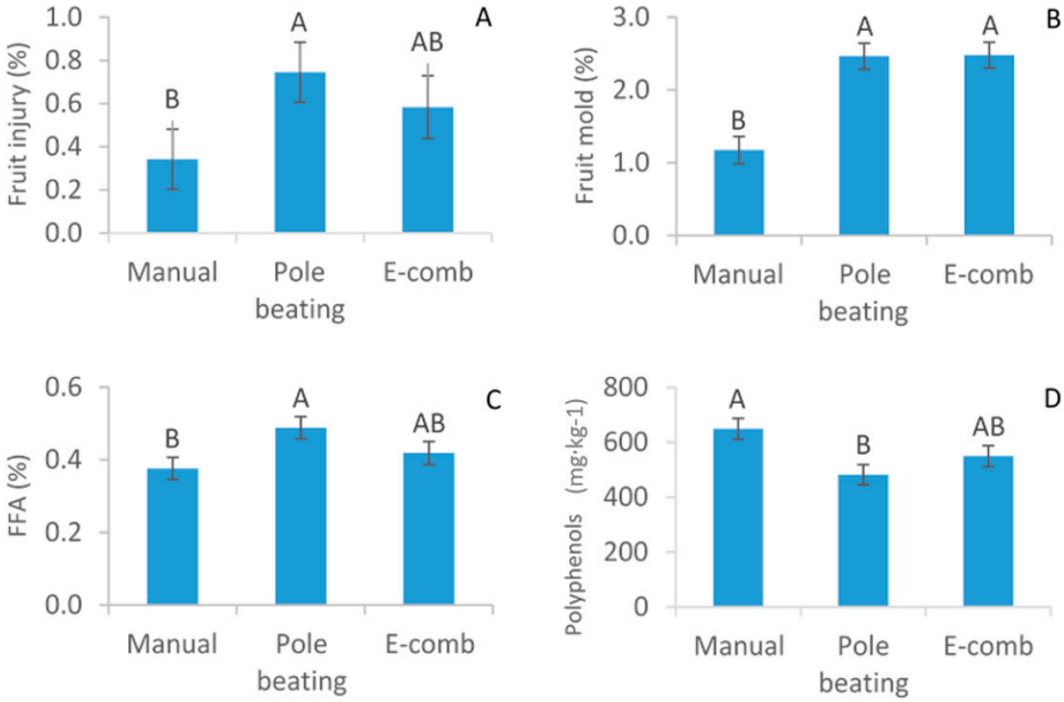

Fig. 2. Effect of the harvest method on fruit injury (A), development of fruit mold (B), oil free fatty acid (FFA) content (C), and olive oil polyphenols (D). Different letters indicate a significant difference between treatment means (Student's paired *t* test at $P < 0.05$). E-comb = electric comb. 1 mg·kg^{-1} = 1 ppm.

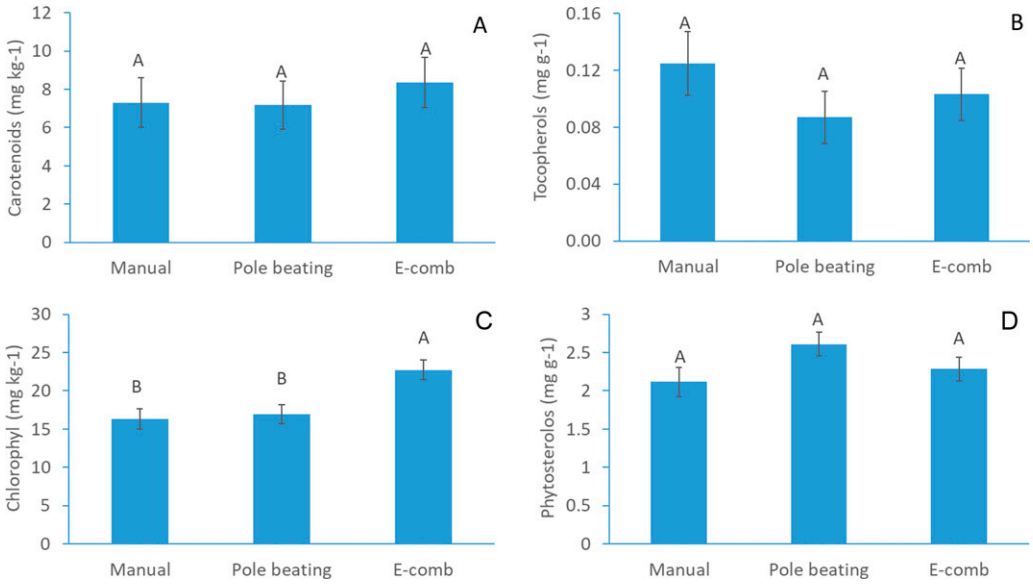

Fig. 3. Effect of the harvest method on total carotenoids (A), tocopherols (B), chlorophyll (C), and phytosterols (D) in the olive oils. Different letters indicate a significant difference between treatment means (Student's paired *t* test at $P < 0.05$). E-comb = electric comb. 1 mg·kg^{-1} = 1 ppm.

We clearly showed that traditional olive orchards could possibly produce high-quality oil. The FFA and sensory assessment values indicated that the oil can be classified as EVOO. However, as shown in Fig. 4A and Tables 2 and 4, the growers' practices resulted in much lower oil quality that did not meet the quality standards of EVOO. The higher pungency and bitterness of the experimentally extracted oil (Table 4) are probably attributable to the high content of phenolic compounds in this oil (Table 2) (Dag et al. 2008).

Three parameters, oil content based on dry weight, FFA values of experimentally and commercially obtained oils, and polyphenol levels in the same oils, indicated that the commercial harvest takes place later than the optimal timing for obtaining high-quality olive oil. In the experimental sample, the oil content in the dry weight was at the maximum level (i.e., 50%). The commercial harvest occurred later than the experimental harvest; therefore, the oil quality could only deteriorate. In 'Souri', the oil content reaches its maximum at an early stage of ripening, and the oil quality begins to deteriorate at a relatively early stage of ripening (Dag et al. 2008). The grower's traditional practice of delaying harvest until late ripening to obtain higher oil yields leads to deterioration in oil quality.

By seeking the "bottlenecks" in farmers' practices that lead to reduced

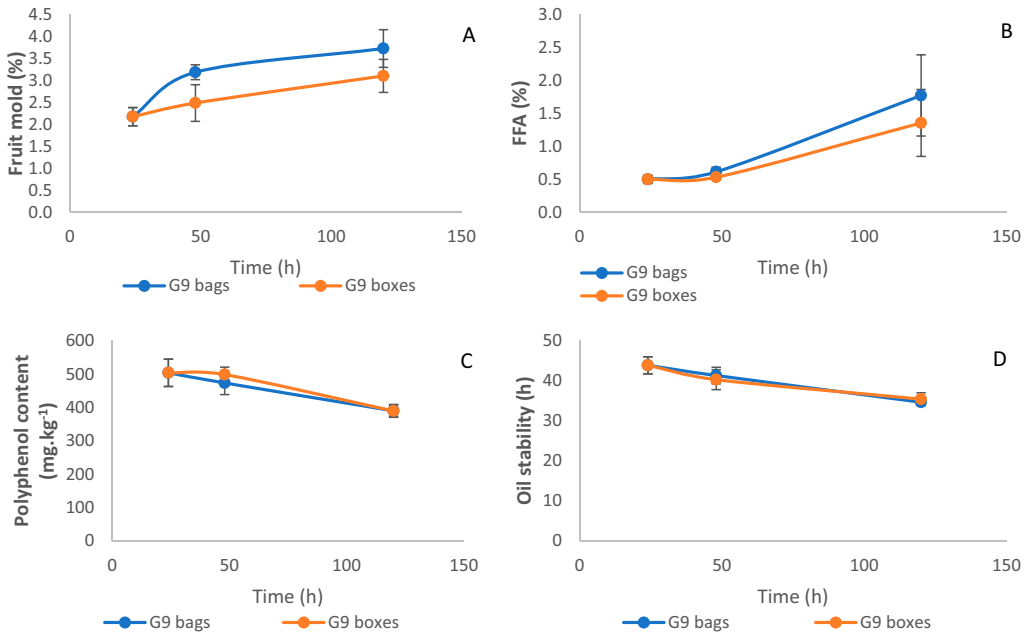

Fig. 4. Effect of olive storage (length and conditions) on fruit mold (A), free fatty acid (FFA) content (B), polyphenols (C) in the oil, and oil stability (D). Means ± *SE* of three replicates (n = 3) are presented. 1 mg·kg^{-1} = 1 ppm.

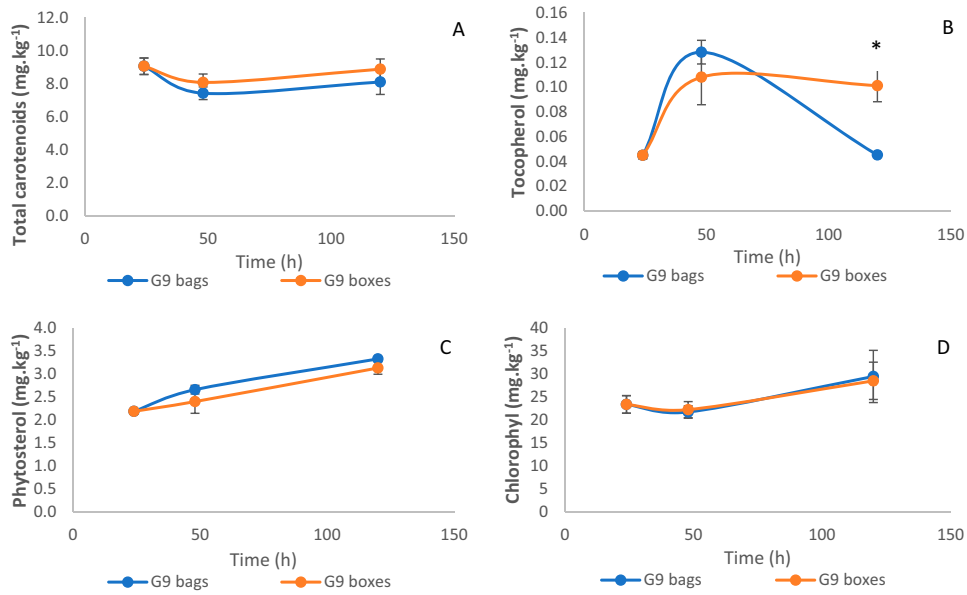

Fig. 5. Effect of olive storage (length and conditions) on total carotenoids (A), tocopherols (B), phytosterols (C), and chlorophyll (D) in the oil. *Significant difference ($P < 0.05$) between treatments within the same time. Means ± *SE* of three replicates (n = 3) are presented. 1 mg·kg^{-1} = 1 ppm. G9 = the origin of the fruit (see Table 1).

oil quality, we isolated two components, harvesting method and fruit storage before milling, in the production chain. The traditional harvesting method of pole beating, which is the prevalent commercial harvesting method, caused substantial fruit injury (Fig. 2A). This injury increased the incidence rates of fruit mold (Fig. 2B), reduced polyphenols (Fig. 2D), and increased FFA (Fig. 2C) levels in the oil compared with those associated with manual picking. Hence, the commercial harvesting practice contributes to the deterioration of oil quality. Using electric combs for harvesting resulted in somewhat better oil quality (Fig. 2), but it was not significant because this method also damaged the fruit. The negative impact of aggressive olive harvesting on oil quality has been described (Dag et al. 2008; Famiani et al. 2020). Two traditional fruit handling practices, delayed shipment of the fruit to the mill and storing the fruit in nonventilated bags, before oil extraction also cause problems. Our results indicated a steady decline in the polyphenol content (Fig. 4C) and oil stability (Fig. 4D) as storage time increased. There was a minor increase in the FFA levels of oil extracted from fruit stored for up to 48 h, followed by rapid deterioration resulting in a sharp increase in FFA values (Fig. 4B); this was further accelerated in fruit stored in bags. Tocopherols also decreased sharply in fruit stored for long periods in bags (Fig. 5B). Poor ventilation played a crucial role in advancing the critical threshold at which aerobic respiration shifts to anaerobic fermentative metabolism through the reductive decarboxylation of pyruvate to ethanol. This process induces the development of negative chemical and sensorial attributes in olive oil (Plasquy et al. 2021).

European Regulation 432/2012 distinguishes olive oils in terms of their effect on health, which depends on their polyphenol content. The oils in this study were characterized by relatively high levels of polyphenols (>250 mg·kg^{-1} oil) (Table 2, Figs. 2D and 4C); therefore, they can be classified as "health-protecting food products." Polyphenols contribute to the stability and shelf life of oil (Gutiérrezet al. 2001), as well as the sensory characteristics (Servili et al. 2009) and health properties (Gorzynik-Debicka et al. 2018) of oil. The high level of polyphenols in traditional orchards is caused by water stress, which enhances polyphenol synthesis. Water stress has been shown to increase the activity of enzymes, including L-phenylalanine ammonia-lyase, which is responsible for the synthesis of phenolic compounds (Tovar et al. 2002).

In the current study, we focused on traditional, small, rain-fed orchards owned for generations by the same families who followed traditional methods. It is difficult to introduce newer cultivation techniques that are now widely adopted for intensive modern cultivation of olives and can improve olive oil quality. Although the results of this study indicated specific methods that can improved oil quality in traditional olive orchards, their implementation remains socially and culturally challenging (Ruz-Carmona et al. 2023).

Conclusions

Olive oil produced from rain-fed, traditional orchards in the Middle East has potentially high value because of its high content of bioactive polyphenols and the potential for branding as PDO EVOO. However, the current study showed that olive growers at traditional orchards in the region apply incorrect practices that reduce the oil quality. These practices includes improper harvest timing, aggressive harvesting, and long storage periods in unventilated bags. To ensure the future existence of these valuable (to heritage and the landscape) orchards, it is important to educate olive growers so they can improve the production chain, thus allowing them to market high-quality PDO EVOO and increase their profitability and resilience.

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