Characterizing of Oil Quality and Fatty Acid Profiles of Old Olive Trees in Palestine

Thameen Hijawi*

Institute of Development Studies, Al-Quds University, P.O. Box 20002, Jerusalem, PALESTINE

Abstract: Olive growing in Palestine plays an important role at social and economic levels. Nevertheless, the quality of olive oil produced in the country has not been fully addressed. This study examined oil content, peroxide values, acid values, fatty acid profile, and total phenolic content for old olive trees located in different climatic regions in Palestine during the years 2008-2010. Oil content was determined using both Soxhlet and Abencor systems. Acid and peroxide values were determined using standard methods. Total phenolic content was determined using the Folin-spectrophotometric method. Gas chromatography was used to analyze the main fatty acids found in olive oil e.g., palmitic, palmitoleic, stearic, oleic, linoleic. Different ratios indicating olive oil quality were also determined e.g., sum ratio of unsaturated fatty acids to the sum of saturated fatty acids; ratio between the sum of monounsaturated fatty acids to the sum of polyunsaturated fatty acids, and the ratio between the oleic to linoleic fatty acids. Significant differences were found between geographic regions for the overall studied oil parameters. Wide variation ranges were obtained for fatty acids in the different West Bank locations in the three years. The major fatty acids in the olive oil samples were found to be oleic, palmitic, stearic, linoleic, and palmitoleic acids. The oil samples were found to contain more oleic acid and less linoleic and linolenic acids that is, more monounsaturated than polyunsaturated fatty acids. Total phenolic content was found to range from 125.0-978.0, 207.4-763.8, and 103.0-747.6 mg/kg in 2008, 2009, and 2010, respectively. The acidity percentage was in the range of 0.10%-1.05%, 0.11%-1.29%, and 0.10%-1.91% in 2008, 2009, and 2010, respectively. Peroxide values ranged from 2.26-13.1, 2.94-14.95, and 2.49-17.21 in 2008, 2009, and 2010, respectively.

Key words: old olives, geographical region, fatty acid profile, olive oil quality, saturated

1 Introduction

The olive tree was native to Asia Minor and spread from Iran, Syria, and Palestine to the rest of the Mediterranean basin 6,000 years ago. It is one of the oldest cultivated trees known in the world, even grown before the invention of written language. Olive (Olea europaea L) is one of the most important crops in the Mediterranean basin, both economically and agriculturally

Both table olives and olive oil are major components of the daily human diet, and olive trees are a dominant landscape component of rural areas across the Mediterranean. In general, traditional olive cultivation is associated with the Mediterranean climate. Out of the 19.5 million tons of olives produced worldwide, 94.6% are produced in the Mediterranean region (54.2% in southern Europe, 25.1% in northern Africa, 15.3% in western Asia). Palestine accounts for 0.46% of this share. In the northern hemisphere, due to the inability of trees to tolerate frost, olive cultivation is limited by winter temperature towards the north and dryness limits its distribution towards the south. Other environmental factors that impact the ability to cultivate olives include temperature regimes during the differentiation of reproductive organs and at flowering and fruiting time, relative humidity and its effect on diseases and soil conditions such as texture, pH and content of organic matter.

In the West Bank of the Palestinian Authority (PA) (Fig. 1), olives are the most important and dominant agricultural crop cultivated in an area of over 88,000 ha, where they produce ca. 10,000 tons of oil per year. There are approximately 70,000 olive growers in the PA. Palestinian areas cultivated with olive trees account for more than 80% of the agricultural land surface, reaching about 76,000 ha. Olive harvests account for about 12% of the total national agricultural output, reaching 20% in the West Bank, and representing about 4.6% of the Palestinian gross domestic
The primary olive productive areas are located in the western and northern West Bank (the western slope of the mountains) that is characterized by a Mediterranean climate. The areas with the largest groves are in Jenin, Nablus, Tulkarem, and Ramallah. Old olive groves and individual olive trees can still be found in Mediterranean, semi-arid and even arid climates in Palestine. A survey of traditionally-cultivated olive groves showed a wide distribution of orchards of landrace cultivars. Trunk circumference is usually a reference to estimate tree age. Some of the surveyed trees were found to have a circumference of over 4 m and are ca. 1000 years or older.

Olive oil, and its main derived product, experienced an increase in popularity due to its organoleptic characteristics that are associated with health benefits. Fatty acid composition varies widely in vegetable oils. Several studies have shown the dietary importance of fatty acid composition in olive oils. Fatty acid composition has been shown to influence the stability of oils, and polyunsaturated fatty acids have been found to contribute to the rancidification of several oils. Fatty acid composition has been found to be responsible for the odors and flavors associated with oil quality.

The approved limits of some fatty acids were published by the European Union and the International Olive Oil Council as well as previously discussed by other researchers. Respect of these limits does not characterize olive oil (particularly extra virgin and virgin as currently defined).

Additionally, fatty acids are associated with oil health beneficial relevance, mainly monounsaturated fatty acids, and to minor constituents such as tocopherols and phenolic compounds. The fatty acid composition of olive oil varies widely depending on the cultivar, maturity of the fruit, genotypes, altitude, climate, and several other factors. The major fatty acids in olive oil are: Oleic acid (C18:1, a monounsaturated omega-9 fatty acid. It makes up 55%-83% of olive oil); linoleic acid (C18:2, a polyunsaturated omega-6 fatty acid that makes up about 3.5%-21% of olive oil).
Oil Quality of Old Olive Trees in Palestine

J. Oleo Sci.

Spain

Tsimidou and Karalostas

extra virgin olive oils produced in different regions of Spain, Italy and Portugal based on their fatty acid content. Tsimidou and Karalostas classified Greek virgin olive oils according to multivariate analyses of the fatty acid composition of the oils. Other researchers (Stefanoudaki et al.) studied the characterization and authenticity of virgin olive oils extracted from the olive varieties Coratina (Italy), Picual (Spain), and Koroneiki (Greece) by matching sensory, physical, chemical, and compositional data within their fatty acid composition.

The objective of the current work is therefore to investigate fatty acid profiles and oil quality parameters (acid value, peroxide values, sterol content, phenolic content from various geographic regions and different olive cultivars).

Several researchers tried to correlate the geographical origin to the fatty acid composition in olive oil. Garcia and Lopez investigated the possibility of distinguishing among extra virgin olive oils produced in different regions of Spain, Italy and Portugal based on their fatty acid content. Tsimidou and Karalostas classified Greek virgin olive oils according to multivariate analyses of the fatty acid composition of the oils. Other researchers (Stefanoudaki et al.) studied the characterization and authenticity of virgin olive oils extracted from the olive varieties Coratina (Italy), Picual (Spain), and Koroneiki (Greece) by matching sensory, physical, chemical, and compositional data within their fatty acid composition.

The objective of the current work is therefore to investigate fatty acid profiles and oil quality parameters (acid value, peroxide values, sterol content, phenolic content) obtained from old olive trees in Palestine over three consecutive years (2008-2010) as affected by different geographical regions. This current work has not been previously investigated.

2 Materials and Methods

2.1 Tree selection

In this research, 15 sites inhabiting old trees in Palestine were chosen from the south to the north. The selected sites include: Sourief, Bait Jala, Bait Reema, Kufr Ein, Beit Anan, Bediah, Kufr Al Diek, Azzoun, Sinieria, Zaita, Bieta, Dier Al Gosoun, Saída, Kufr Ra’ai, and Berqien. From each site, 10 trees were selected according to the trunk perimeter criteria consisting of 150 cm and above.

2.2 Site and tree identification

Each selected tree in each site was identified by a tree code, composed of 11 numbers (xxx yyyy yyyy zzz n) where xxx represents the province, yyyy represents the village in each province and zzz represents the farmer’s name in each village, while n is a serial number representing the tree’s number in each field. The following information identified GPS marking for coordinates, tree height, trunk perimeter, and pressure.

2.3 Tree sampling and analysis

During the harvest, each selected tree was sampled as follows: around 2 kg of olive fruit was sampled from each tree.

2.4 Olive oil analysis

One kg of olives from the 2 kg olive sample was taken to a laboratory and kept overnight in a refrigerator at 4°C. The fruits were crushed (electric hammer crusher, 4 mm sieve, MC2, Seville, Spain). Uniform paste was divided with about 300 g used to determine water and oil content and 700 g were used for mechanical oil extraction (ABENCOR system, MC2, Seville, Spain). The paste was mixed with 300 ml tap water for 20 min at 30°C, then centrifuged for 60 sec at 3500 rpm. Liquids were placed in a cylinder until phase separation. Oil was decanted for chemical analyses and kept in a glass bottle at 15°C until analysis.

2.5 Determination of water and oil content

In determining water and oil content, the paste was weighed and placed in a drying oven for 48 hr at 105°C. It was then weighed again. Water loss was calculated. Weighed dry paste was placed in a Soxhlet apparatus for 6 hr under hexane for oil extraction. The organic matter was weighed and oil content calculated.

2.6 Determination of free fatty acids (acidity levels)

Free fatty acids (FFA), expressed as the percentage of un-bonded oleic acid of the total fatty acids, was determined by dissolving a 2.2 g oil sample in 15 ml EtOH-diethyl ether mixture with addition of 1% phenolphthalein indicator, then titration with 0.01N ethanolic KOH until pinkish color, according to the EU official method.

2.7 Determination of peroxide value

The peroxide number, millimoles of active oxygen in one kg of oil was determined according to the EU official method. About 1.2 mL of oil was dissolved in 25 mL solvent mixture (Acetic acid:iso-octane 3:2 ratio) with the addition of 250 μL saturated KI solution. The reaction was stopped after 1 min by adding 250 μL of 1% starch solution. The mixture was then titrated with Na₂S₂O₃ (0.01N) until the dark brown color of the original mixture disappeared.

2.8 Determination of total phenolic content

For determining the total content of polyphenol compounds in oil samples, 275 μL oil were dissolved in 500 μL hexane then 350 μL methanol (60%) was added. Strong vortex emulsifies the mixture. After 3 min of centrifugation at 14000 rpm, the lower methanolic phase that contain phenolic compounds was kept. The lipidic phase underwent a second methanolic extraction where 300 μL hexane was added to the combined extract to remove the remain-

J. Oleo Sci.
The content of total polyphenols in the extract was determined through a Folin-Ciocalteu Reagent (FCR), using a modified method\(^\text{19}\). To 200 μL extract, 3 mL water and 250 μL FCR were added and incubated for 5 min. Then, 750 μL of Na\(_2\)CO\(_3\) (20%) was added and incubated for 10 min. Finally, 950 μL water was added and incubated for another 10 min, the absorbance at 735 nm was measured using a spectrophotometer. Total phenolic content is expressed as mg Catechin per kg oil.

### 2.9 Determination of fatty acids of the oil samples

Methylated fatty acids (FAME) profile was determined according to the IOC official method\(^\text{20}\), using Gas Chromatograph (model 7890A Agilent technologies, USA) on a DB23 capillary column (60 m×0.25 mm, 0.25 μL film; J&W Scientific, Folsom, CA, USA) and FID (Flame ionization detector). Approximately 0.1 g oil was dissolved in 2.0 mL n-heptane (GC grade, Merck) with 0.2 ml methanolic KOH (\(\text{2N}\)). After strong vortex and 30 sec wait, the upper fraction containing FAME was collected and analyzed. Peak identification and retention times were compared to external standards (FAME mix C8-C24).

### 2.10 Environmental measurements

Environmental information collected from the data environmental database included aspect, slope, altitude, lithology, mean day temperature in January, mean day temperature in August, maximum temperature in June, minimum temperature in January, and precipitation.

### 2.11 Statistical analysis

Three samples of each treatment were independently analyzed in each sampling. All the determinations were carried out in triplicate. All statistical analyses were carried out using SAS (SAS Institute Inc., Cary, USA, Release 8.02, 2001). Mean comparisons were carried out using the GLM procedure, treating main factors separately using one-way analysis of variance (ANOVA). Differences were considered significant if P values were lower than 0.05. The Bonferroni procedure was employed with multiple t-tests in order to maintain an experiment-wise of 5%. Pearson correlations were calculated to test the relation between quality parameters and fatty acids in olive oil. The NOMISS option was used in order to obtain results consistent with subsequent multiple regression studies.

### 3 Results and Discussion

Olive fruit was obtained from 15 geographical locations in West Bank ranging from northern to middle and southern West Bank. In Palestine, three climatic zones can be recognized including the Mediterranean zone in the western slopes of the mountains running north-south, the semi-arid (the top of the eastern slopes) and arid zones in the middle and the bottom of the eastern slopes. In general, the local climate is characterized by dry summers with rainy and cold winters. While annual precipitation in the semi-arid and arid environments is low (200-300 and < 100 mm/year, respectively), it is more diverse in the Mediterranean region. There, topography affects annual rainfall which ranges from ca. 350 mm/year in some districts to more than 800 mm/year. In addition, summer and winter temperature regimes differ along north-south and west-east transects. Winters are harsher in the mountains of the north and east while the coastal plain is characterized by relatively warm winters (>8°C). The average annual temperature in the inner plain is higher but relative humidity decreases with increasing distance from the Mediterranean Sea towards the east. Traditional olive groves in Palestine are mainly concentrated in the mountainous areas, inland and southern districts of the region, in areas with more than 350 mm rainfall/year\(^\text{17}\).

#### 3.1 Percentage of oil and water content in olive fruit

Results showed that the percentage of oil content using the Abencor system in 2008 was not significantly different among the various locations in West Bank, with the exception of Sourief which is significantly lower than other locations. In 2009 and 2010 on the other hand, significant differences in oil content percentage were observed between some locations in West Bank as shown in Table 1. In 2010, Bergien recorded the lowest oil content percentage (14.4%) while Bait Reema, Beit Anan had the highest percentage (about 26%). In 2008 on the other hand, the lowest percentage of oil was found in Sourief while the highest percentage was found in Sinieria. In 2009, the amount of olive fruit on olive trees was so low that very modest amounts of olive oil were produced that year, this explains why olive oil was only collected from six regions in the West Bank as shown in Table 1, compared to the years 2008 and 2010. The oil percentage by the Abencor system ranged from 17.0%-27.8% in 2008; from 14.4%-26.3% in 2010, and from 18.2%-27.7% in 2009.

Regarding the percentage of olive oil produced from the Soxhlet extraction method of olive fruit collected from West Bank locations, results showed that oil content in 2008, 2009 and 2010 was significantly different in some locations (see Table 1). The percentage of oil in Sourief in 2008 and 2010 was found to be significantly lower than other regions (23.3% and 20.9% for 2008 and 2010, respectively) while the percentage of oil in Sinieria in 2008 (31.9%) and in Bait Reema (32.1%) in 2010 was found to be significantly higher than other regions. Concerning the percentage of oil content in 2009 as reported above, the amount of olive oil produced in this year was low, this explains why olive oil was collected from few regions under
study (Table 1), compared to the years 2008 and 2010. The oil percentage produced by Soxhlet extraction method ranged from 23.3%-31.9% in 2008, 23.9%-33.4% for 2009, and from 20.4%-32.1% in 2010.

It is interesting to compare oil content obtained from the two extraction methods (chemical extraction method/Soxhlet compared to the mechanical/Abencor extraction method). Results showed that Soxhlet is superior in extracting olive oil from olive fruit containing the highest oil content of 33.4% compared to 27.8% for the Abencor extraction system. Additionally, the oil content of the Soxhlet method ranged from 20.4%-33.4% compared to 14.4%-27.8% for the Abencor method over the three years.

The water content of olive fruit samples was also determined. Results showed that the water content of olive fruit samples obtained in 2008 ranges from 28.0%-39.6%, while in 2010 it ranges from 24.3%-41.8%, and for those obtained in 2009 water content ranged from 29.5%-41.1%. Significant differences in the water content of olive oil samples collected from different studied locations in 2008, 2009, and 2010 were observed. The highest water content of olive fruit samples collected in 2008-2010 was found in samples obtained from Beit Anan in 2010 (see Table 1).

### Table 1

| Lo* | Oil Content (%) (Abencor) | Oil Content (%) (Soxhlet) | Water Content (%) |
|-----|--------------------------|---------------------------|------------------|
|     | 2008 | 2009 | 2010 | 2008 | 2009 | 2010 | 2008 | 2009 | 2010 |
| 1   | 17.0 | -    | 16.0 | 23.3 | -    | 21.0 | 39.6 | -    | 41.8 |
| 2   | 21.6 | 20.3 | 18.1 | 26.9 | 23.9 | 25.2 | 34.6 | 37.0 | 39.8 |
| 3   | 25.8 | -    | 26.3 | 29.6 | -    | 32.1 | 28.0 | -    | 31.5 |
| 4   | 24.1 | -    | 23.9 | 28.4 | -    | 29.3 | 29.1 | -    | 29.8 |
| 5   | 24.8 | 24.8 | 26.1 | 28.2 | 31.5 | 30.9 | 36.4 | 36.3 | 24.3 |
| 6   | 27.5 | 18.2 | 24.4 | 30.6 | 27.6 | 28.9 | 28.5 | 41.1 | 30.0 |
| 7   | 24.0 | 27.7 | 17.3 | 28.0 | 33.4 | 23.5 | 29.7 | 29.5 | 34.7 |
| 8   | 24.1 | 22.0 | 21.1 | 28.6 | 29.1 | 26.2 | 33.0 | 36.6 | 35.0 |
| 9   | 25.7 | 26.6 | 24.0 | 28.3 | 30.8 | 28.2 | 31.7 | 32.2 | 35.2 |
| 10  | 22.0 | -    | 21.2 | 25.4 | -    | 27.6 | 36.4 | -    | 34.8 |
| 11  | 24.7 | -    | 23.7 | 27.4 | -    | 30.7 | 36.6 | -    | 35.4 |
| 12  | 24.5 | -    | 14.4 | 28.1 | -    | 20.4 | 34.0 | -    | 40.5 |
| 13  | 24.3 | -    | 20.6 | 28.6 | -    | 26.5 | 32.8 | -    | 35.4 |
| 14  | 24.7 | -    | 21.2 | 29.9 | -    | 27.8 | 33.2 | -    | 34.3 |
| 15  | 27.8 | -    | 21.0 | 31.9 | -    | 28.6 | 30.3 | -    | 33.4 |

* Locations: Sourief (1), Bait Jala (2), Bait Reema (3), Kufr Ein (4), Beit Anan (5), Bediah (6), Kufr Al Diek (7), Zaita (8), Bieta (9), Dier Al Gosoun (10), Saida (11), Berqien (12), Kufr Ra’ai (13), Azzoun (14), Azzoun (15).

### 3.2 Total phenolic content (TPC) of olive oil samples

Results in Table 2, show that the total phenolic content of olive oil is affected by geographical location, where it was found that there are significant differences in total phenolic content of olive oil among the locations in all years. The maximum TPC value was found for oil samples obtained from Beit a in 2008 (604.4 mg/kg), while the lowest was found in Kufr Al Diek (229.1 mg/kg). For oil samples in 2009 and 2010, the TPC ranged from 291.7-607.6 and 201.7-580.6, respectively. These results prove the effect of geographical regions on total phenolic content of olive oil. The highest TPC of all oil samples in the three years 2008-2010 was found for Zaita (607.6 mg/kg) obtained in 2009 while the lowest TPC value was found in Saida (201.7 mg/kg) obtained in 2010. The highest value is three-fold compared to the lowest value which proves the impact of geographic regions.

Phenolic compounds are important secondary metabolites present in olive oil. They are a complex class of chemicals including a hydroxyl group on a benzene ring. Phenolic compounds are defined based on metabolic origin and these substances derive from the shikimate pathway and phenylpropanoid metabolism. Phenolic compounds are a complex mixture of compounds with different chemical structures obtained from oil by extraction with methanol-water. Phenolic compounds are related to the stability of oil in addition to its biological properties. Most phenolic
Dabbou et al. studied the antioxidant capacity of virgin olive oil obtained from three different regions. Dagdelen measured the total concentration of polyphenol in some samples of Palestinian olive oil and results showed that TPC in olive oil ranges from 150-300 mg/kg which is in accordance with the literature value. Many studies were conducted on TPC of olive oil samples from different regions. Dagdelen studied phenolic content of virgin olive oil obtained from three different locations in Turkey. The total phenolic content was found to reach between 159.99-189.64 mg gallic acid equivalent/kg. Houshia and Qutit studied pheno-meric extracts of four Tunisian olive oils and total phenolic amount and composition of olive oil harvested in 2008, 2009 and 2010 (Table 2). Regarding the acidity percentage for olive oil samples investigated in this study, results showed that olive oil samples obtained in 2009 were not significantly dissimilar between different regions, while in 2010, oil samples from Beit Anan were significantly higher than all other samples from different regions (see Table 2). In 2008 on the other hand, results showed that two categories of geographic regions were observed where the acidity percentage of the first category was significantly higher than the other indicated by capital letters (A and B). The highest acidity percentage values in 2008 were 0.42 for samples obtained from Sinieria while the lowest value was obtained from samples in Sourief (0.17). The acidity percent in 2009 ranged from 0.30-0.43%, while in 2010 it ranged from 0.26%-1.14%

The acidity of olive oil indicates the percentage of oleic acid in an oil and is the primary indicator of its quality which should be less than 0.8% in extra virgin olive oil. There are many factors that affect the acidity percentage of olive oils e.g. geographic region, health status of olives, harvesting technique, as well as storage time and conditions. Olive collection also has a profound effect on the quality of the resulting oil, with hand picking serving as.

### Table 2: Polyphenols content, acidity and peroxide value of olive fruits collected from old olive trees in three years (2008-2010) located in different locations in Palestine (n = 10).

| Lo* | Polyphenols (mg/kg oil) | Acidity (%) | Peroxide (meq. O₂/Kg) |
|-----|------------------------|-------------|-----------------------|
|     | 2008 | 2009 | 2010 | 2008 | 2009 | 2010 | 2008 | 2009 | 2010 |
| 1   | 341.1 | -    | 345.1 | 0.17 | -    | 0.26 | 7.3  | -    | 3.4  |
| 2   | 549.8 | 334.2 | 474.0 | 0.21 | 0.43 | 0.33 | 6.3  | 7.8  | 4.5  |
| 3   | 491.1 | -    | 441.4 | 0.18 | -    | 0.36 | 8.4  | -    | 4.7  |
| 4   | 392.1 | -    | 298.6 | 0.18 | -    | 0.56 | 5.0  | -    | 4.9  |
| 5   | 506.9 | 473.9 | 238.3 | 0.26 | 0.42 | 1.14 | 5.1  | 7.2  | 12.1 |
| 6   | 355.7 | 291.7 | 261.8 | 0.27 | 0.39 | 0.52 | 4.1  | 8.6  | 7.4  |
| 7   | 229.1 | 344.7 | 292.3 | 0.23 | 0.30 | 0.27 | 5.3  | 6.4  | 4.5  |
| 8   | 521.6 | 607.6 | 406.0 | 0.21 | 0.31 | 0.24 | 5.8  | 6.2  | 4.8  |
| 9   | 604.4 | 549.8 | 580.6 | 0.19 | 0.37 | 0.31 | 7.8  | 5.4  | 4.4  |
| 10  | 375.0 | -    | 221.8 | 0.21 | -    | 0.40 | 6.4  | -    | 5.6  |
| 11  | 583.7 | -    | 201.8 | 0.28 | -    | 0.44 | 5.4  | -    | 6.0  |
| 12  | 428.6 | -    | 289.7 | 0.27 | -    | 0.28 | 5.3  | -    | 4.2  |
| 13  | 339.5 | -    | 316.7 | 0.24 | -    | 0.32 | 5.0  | -    | 4.5  |
| 14  | 342.4 | -    | 350.7 | 0.26 | -    | 0.35 | 4.0  | -    | 4.8  |
| 15  | 297.0 | -    | 247.1 | 0.42 | -    | 0.43 | 6.3  | -    | 9.7  |

* Locations: Sourief (1), Bait Jala (2), Bait Reema (3), Kufr Ein (4), Beit Anan (5), Bediah (6), Kufr Al Diek (7), Zaita (8), Bieta (9), Dier Al Gosoun (10), Saida (11), Berqien (12), Kufr Ra‘ai (13), Azzoun (14), Sinieria (15).
Oil Quality of Old Olive Trees in Palestine

J. Oleo Sci.

the best technique. If the collection is delayed, the natural fall of the fruit takes place and a series of alterations deteriorate the quality of the oil, particularly its acidity\(^{(37)}\). Free oleic acid in the oil can increase if lipase enzymes act. The process can be intensified if the olive suffered a cellular injury: insect attack, injury during collection and transport, as well as poor agricultural and environmental status. The lipase enzymatic activity is also favored by fairly high temperatures, between 30°C and 40°C\(^{(39)}\).

Olive oil is classified as extra virgin when free acid content is less than 0.8% and is classified as virgin if its acidity is between 0.8%-2.0%. Olive oil samples analyzed in our study were found to be of extra virgin quality with an acidity percent reaching less than 0.8% while only one sample was found to have an acidity percentage higher than 0.8% which was from Beit Anan in 2010\((1.14)\).

Peroxide values (expressed as mequivalent \(O_2\) per kg) were also determined for the oil samples (Table 2). In 2008, results showed that peroxide values were not significantly different between the various locations indicated. In 2009 and 2010 significant differences in the peroxide values were observed between the various locations. In 2009, the highest peroxide value was found to be 8.6 from Bediah while the lowest value was 5.4 from Beit. On the other hand, in 2010, the highest peroxide value was 12.1 from Beit Anan while the lowest value was 3.4 from Sourief.

Results of this study showed a wide range of peroxide values for oil samples from different regions and different harvesting years, where the highest value and lowest values were identified as 12.1 (from Beit Anan in 2010) and 3.4 (from Sourief in 2010), respectively.

Olive oil with a peroxide value of less than 20 is classified as extra virgin according to standards established by the International Olive Oil Council. This indicates that all samples investigated in this study are of extra virgin olive oil quality.

A very low peroxide value is desirable. The starting point of the peroxidation process takes place during oil pressing and is affected by storage conditions of the oil\(^{(31)}\). The peroxide content (PV), measured in milliequivalents of active oxygen per kilogram determines the initial oxidation of the oil. The peroxidation of the oil primarily arises due to the oxidation process, high temperature, and visibility to light. Contact with metal surfaces can also cause faster oil oxidation. The lower the peroxide value the longer the oil will retain its shelf life and will delay the possibility of rancidity. A high peroxide value usually indicates poor processing and that the quality of the oil is low. Setting a low peroxide value standard for olive oil means that it will be more stable and if correctly-stored, shelf life will be extended. High peroxide levels indicate that oil has been damaged by free radicals and will give rise to aldehydes and ketones that can cause oil to smell musty and rancid. These reactions are accelerated by heat, light, and air (oxidation). Oxida-

tion is a natural process. It occurs more slowly, however, in extra virgin olive oils (VOOs) with the highest levels of oleic acid and polyphenols\(^{(39)}\).

The quality indices (free acidity, peroxide value, TPC) of the obtained olive oils were analyzed to obtain a more complete characterization of these oil samples. Results revealed that all the analyzed VOOs were classified in the “extra virgin” category according to the regulated physico-chemical parameters.

3.4 Fatty acid composition

Different fatty acids such as palmitic acid\((C16:0)\), palmitoleic acid\((C16:1)\), stearic acid\((C18:0)\), oleic acid\((C18:1)\), linoleic acid\((C18:2)\), linolenic acid\((C18:3)\), arachidic acid\((C20:0)\), behenic acid\((C22:0)\) and lignoceric acid,\((C24:0)\) expressed as percentage of fatty acid methyl esters, were monitored in this study.

The major component of olive oil is a mixture of fatty acids. The fatty acid composition of olive oil varies widely depending on the cultivar, maturity of the fruit, altitude, climate, and several other factors\(^{(35)}\). The major fatty acids in table olives are oleic, palmitic, stearic, linoleic, and palmitoleic acids\(^{(39)}\). Because table olives are mainly composed of MUFAs, the consumption of table olives can prevent and reduce the risk of cardiovascular diseases, regulate cholesterol levels, stimulate transcription of LDL-cholesterol receptor mRNA and reduce breast cancer risk\(^{(45)}\).

Several studies have shown the dietary importance of fatty acid composition of lipids. A diet rich in monounsaturated fatty acids may reduce low-density lipoprotein cholesterol and total cholesterol without altering beneficial high-density lipoprotein cholesterol levels\(^{(41)}\). Fatty acid composition has been shown to influence the stability of oils, and polyunsaturated fatty acids have been found to contribute to the rancidification of several oils\(^{(42, 43)}\). Fatty acid composition has also been found to be responsible for odors and flavors associated with oil quality.

3.5 Content of palmitic\((C16:0)\) and stearic acid\((C18:0)\) in oil samples

Content of palmitic acid\((C16:0)\) and stearic acid\((C18:0)\) of olive fruits collected from old olive trees over three years (2008-2010) from different locations in Palestine were determined with results shown in Table 3. The range of palmitic acid content in 2008 was 11.9%-14.6% for olive fruits collected from Kufr Aldiek and Kufr Ein, respectively, while it ranged from 12.2%-14.9% for 2009 olive oil samples from Bait Jala and Bediah, respectively. In 2010 on the other hand, the highest palmitic acid content identified was 14.9% for Saida and the lowest was 10.9% for Beit Anan. The range of palmitic acid content in the three years from the 15 locations was 10.9%-14.9%, and this concurs with the literature values of palmitic acid (7.5-20% of olive oil).
The amount of palmitic acid obtained in our study is consistent with many other studies\(^\text{12, 40, 44}\). Palmitic acid \(\text{C}_{16:0}\) is the principal saturated fatty acid in olive oil that is responsible for its figureability at low temperatures. There are few exceptions as palmitic acid content depends heavily on genetic factors. Palmitic fatty acids, important for the nutritional properties of olive oil, showed a crucial role in the characterization of olive oils.

Stearic acid \(\text{C}_{18:0}\) content was also determined for olive oil samples and results showed that this content is not significantly different in the various locations in 2009, while significant differences in the content of stearic acid were observed among locations in 2008 and 2010. The stearic acid content ranged from 2.2\(^\text{-}\)4.5\(^\text{mg fatty acid/100 mg olive oil}\) in oil samples from Kufur Ein in 2008 and Dier Al Gosoun in 2008, respectively (Table 3). The content of stearic acid in oil samples analyzed in this study agrees with the literature values\(^0.5\text{-}5\text{mg fatty acid/100 mg olive oil}\).

Results showed that the most abundant content of this fatty acid was measured in oils from the years 2010 and 2008 as compared to 2009.

3.6 Content of \(\text{trans}\) and \(\text{cis}\) palmitoleic acid \(\text{C}_{16:1}\) of olive oil samples

Additionally, content of \(\text{trans}\) and \(\text{cis}\) palmitoleic acid \(\text{C}_{16:1}\) of olive oil samples collected from old olive trees in three years (2008-2010) in different locations in the West Bank was determined, as results are shown in Table 4. Results showed significant differences in the content of \(\text{trans}\) palmitoleic acid among locations indicated by capital letters. In 2008, the range reached 0.10-0.56, while in 2009 and 2010 the range reached 0.08-0.12, and 0.09-0.13, respectively. Regarding \(\text{cis}\) palmitoleic acid \(\text{C}_{16:1}\), significant differences were also observed in their content among the various locations indicated by capital letters in Table 4.

In 2008, the range of \(\text{cis}\) palmitoleic acid \(\text{C}_{16:1}\) reached 0.41-1.12 compared to 0.47-0.79 and 0.35-0.72 for 2009 and 2010, respectively.

Comparing the amounts of \(\text{cis}\) and \(\text{trans}\) palmitoleic acid \(\text{C}_{16:1}\), it is obvious from the results that \(\text{cis}\) content is higher than the \(\text{trans}\) isomer of palmitoleic acid \(\text{C}_{16:1}\); the range of \(\text{cis}\) is 0.35 to 1.12 compared to 0.08-0.56 for \(\text{trans}\) isomer for pooled samples from all locations in the three years.

Most of the natural unsaturated fatty acids in edible oils are non-conjugated acids with a \(\text{cis}\) structure. Meanwhile,
natural TFAs account for only a very small fraction of natural unsaturated fatty acids. The cis-trans isomerization of unsaturated fatty acids in edible oils is not expected in most cases because an excessive intake of trans fatty acids (TFAs) has been associated with the increased risk of coronary heart disease (CHD), sudden death, diabetes mellitus and increased markers for systematic inflammation. The sum of cis and trans palmitoleic acid (C16:1) is shown in Table 5. The range of the sum was found as 0.52-1.23, 0.58-0.86, 0.48-0.82, for 2008, 2009, and 2010, respectively. The results of this study are in agreement with the literature concerning oleic acid composition of olive oil which ranges from 55%-83% as well as previous investigators that documented a range of 64.4%-68.9% for oleic acid. Oleic acid is well-recognized as the most important fatty acids.

### Table 4: Trans and cis palmitoleic acid (C16:1) contents (in mg fatty acid/100 mg olive oil) of olive fruits collected from old olive trees in three years (2008-2010) located in different locations in Palestine (n = 10).

| Lo* | C16:1 trans (%) | C16:1 cis (%) |
|-----|-----------------|--------------|
|     | 2008  | 2009  | 2010  | 2008  | 2009  | 2010  |
| 1   | 0.16  | –     | 0.10  | 0.94  | –     | 0.72  |
| 2   | 0.27  | 0.12  | 0.11  | 1.01  | 0.47  | 0.59  |
| 3   | 0.14  | –     | 0.10  | 0.97  | –     | 0.52  |
| 4   | 0.11  | –     | 0.11  | 1.12  | –     | 0.48  |
| 5   | 0.10  | 0.09  | 0.13  | 0.51  | 0.65  | 0.35  |
| 6   | 0.11  | 0.08  | 0.11  | 0.43  | 0.79  | 0.53  |
| 7   | 0.12  | 0.09  | 0.10  | 0.41  | 0.58  | 0.58  |
| 8   | –     | 0.09  | 0.10  | –     | 0.63  | 0.50  |
| 9   | –     | 0.10  | 0.09  | –     | 0.49  | 0.46  |
| 10  | 0.25  | –     | 0.11  | 0.57  | –     | 0.64  |
| 11  | 0.56  | –     | 0.09  | 0.45  | –     | 0.71  |
| 12  | 0.10  | –     | 0.10  | 0.49  | –     | 0.65  |
| 13  | 0.11  | –     | 0.11  | 0.45  | –     | 0.49  |
| 14  | 0.10  | –     | 0.10  | 0.50  | –     | 0.57  |
| 15  | 0.11  | –     | 0.09  | 0.46  | –     | 0.65  |

* Locations: Sourief (1), Bait Jala (2), Bait Reema (3), Kufr Ein (4), Beit Anan (5), Bediah (6), Kufr Al Diek (7), Zaita (8), Bieta (9), Dier Al Gosoun (10), Saida (11), Berqien (12), Kufr Ra’ai (13), Azzoun (14), Sinieria (15).

### 3.7 Content of trans and cis oleic acid (C18:1) of olive oil samples

Trans and cis oleic acid (C18:1) contents of olive oil samples were also determined (Table 6). Table 6 revealed that cis oleic acid content is lowest in Saida (63.4%) and increases in other regions, reaching 68.2% in Kufr Al Diek in 2008. In 2009, its lowest content was found to be 66.6% in Zaita and the highest content reached 69.3% in Bait Jala. In 2010 on the other hand, the range of cis oleic acid was 60.4-68.2.

Trans oleic acid was also found to be significantly different between the olive oil samples collected from different locations under investigation; in 2008 the lowest value was found in Kufr Al Diek (1.3) and the highest in Kufr Ein (3.0). In 2009 and 2010, the range of trans oleic acid was 1.5-2.1 and 0.5-1.8, respectively. As expected, the amounts of trans oleic acid is very minor compared to cis oleic acid. The sum of cis and trans oleic acid (C18:1) is shown in Table 7. The range of the sum was found to be 65.0-69.6, 68.4-70.7, 62.1-68.9 for 2008, 2009, and 2010, respectively. The results of this study are in agreement with the literature concerning oleic acid composition of olive oil which ranges from 55%-83% as well as previous investigators that documented a range of 64.4%-68.9% for oleic acid.
acid in olive oil and is associated with its high nutritional value and oxidative stability\(^{50,51}\). An olive variety is considered to have a high oleic acid content if C18:1 is about 65% and above\(^{52}\). In the present study, most of the samples studied have an oleic acid percentage higher than 65% which is categorized as a high oleic acid content.

In particular, high levels of MUFAs (mainly oleic acid), which have health benefits and are important for human nutrition, are among the major components of the Mediterranean diet. They also play an important role in the nutritional value of table olives\(^{16,44,49}\).

### 3.8 Content of linoleic (C18:2), and linolenic (C18:3) of olive oil samples

The content of linoleic (C18:2) and linolenic (C18:3) acids in olive oil samples were also determined (Table 8) and significant differences were observed in the amounts of either linoleic or linolenic among the different locations. The range of linoleic acid content in 2008, 2009, and 2010 was determined as: 9.3-12.8, 9.1-10.7, 11.1-14.1, respectively. The range of content of linolenic acid in 2008, 2009, and 2010 was 0.62-0.93, 0.53-0.69, and 0.65-0.89, respectively.

Polyunsaturated fatty acids like linoleic (C18:2), and linolenic (C18:3) were present in olive oil but the concentration of linoleic (C18:2) is higher than the concentration of linolenic (C18:3); our results showed that the content of linoleic ranges from 9.1-14.1 compared to 0.53-0.93 for lin-

### Table 5

**Sum of cis and trans of Palmitoleic acid content (C16:1)** (in mg fatty acid/100 mg olive oil) of olive fruits collected from old olive trees in three years (2008-2010) located in different locations in Palestine (n = 10).

| Lo* | 2008 | 2009 | 2010 |
|-----|------|------|------|
| 1   | 1.09 | -    | 0.82 |
| 2   | 1.17 | 0.59 | 0.69 |
| 3   | 1.11 | -    | 0.62 |
| 4   | 1.23 | -    | 0.60 |
| 5   | 0.62 | 0.71 | 0.48 |
| 6   | 0.54 | 0.86 | 0.64 |
| 7   | 0.52 | 0.67 | 0.68 |
| 8   | -    | 0.72 | 0.60 |
| 9   | -    | 0.58 | 0.55 |
| 10  | -    | -    | 0.75 |
| 11  | 1.01 | -    | 0.80 |
| 12  | 0.59 | -    | 0.74 |
| 13  | 0.56 | -    | 0.60 |
| 14  | 0.59 | -    | 0.67 |
| 15  | 0.57 | -    | 0.74 |

* Locations: Sourief (1), Bait Jala (2), Bait Reema (3), Kufr Ein (4), Beit Anan (5), Bediah (6), Kufr Al Diek (7), Zaita (8), Bieta (9), Dier Al Gosoun (10), Saida (11), Berqien (12), Kufr Ra’ai (13), Azzoun (14), Sinieria (15).

### Table 6

**Trans and cis oleic acid (C18:1) contents (in mg fatty acid/100 mg olive oil)** of olive fruits collected from old olive trees in three years (2008-2010) located in different locations in Palestine (n = 10).

| Lo* | C18:1 cis | C18:1 trans |
|-----|-----------|-------------|
|     | 2008      | 2009        | 2010      | 2008     | 2009     | 2010     |
| 1   | 65.4      | -           | 64.4      | 2.6      | -        | 1.4      |
| 2   | 65.7      | 69.3        | 64.9      | 2.7      | 1.5      | 1.6      |
| 3   | 65.6      | -           | 64.5      | 2.6      | -        | 1.4      |
| 4   | 64.9      | -           | 66.4      | 3.0      | -        | 0.5      |
| 5   | 68.1      | 67.3        | 68.2      | 1.4      | 1.7      | 0.7      |
| 6   | 67.8      | 67.3        | 64.8      | 1.3      | 2.1      | 1.0      |
| 7   | 68.3      | 66.8        | 63.8      | 1.3      | 1.8      | 1.5      |
| 8   | -         | 66.6        | 65.5      | -        | 1.8      | 1.2      |
| 9   | -         | 67.3        | 64.7      | -        | 1.6      | 1.1      |
| 10  | 66.9      | -           | 63.5      | 1.3      | -        | 1.4      |
| 11  | 63.4      | -           | 60.4      | 1.6      | -        | 1.8      |
| 12  | 67.1      | -           | 63.6      | 1.5      | -        | 1.2      |
| 13  | 66.8      | -           | 64.9      | 1.7      | -        | 0.9      |
| 14  | 68.0      | -           | 64.6      | 1.5      | -        | 1.5      |
| 15  | 66.6      | -           | 62.4      | 1.4      | -        | 1.5      |

* Locations: Sourief (1), Bait Jala (2), Bait Reema (3), Kufr Ein (4), Beit Anan (5), Bediah (6), Kufr Al Diek (7), Zaita (8), Bieta (9), Dier Al Gosoun (10), Saida (11), Berqien (12), Kufr Ra’ai (13), Azzoun (14), Sinieria (15).
unsaturated (MUFA) than polyunsaturated fatty acids (PUFA). This makes olive oil more resistant to oxidation. The greater the number of double bonds in the fatty acids, the more unstable the oil becomes and easily broken down by heat, light, and other factors. It is generally accepted that cooler areas will yield oil with higher oleic acid than warmer climates, which means that a cool olive oil region may have more MUFA content than oil in warmer regions\(^\text{[35]}\).

Fatty acid composition is important for the commercial properties of oil and can influence the stability of oils due to the contribution of PUFAs to oil rancidity. In addition, several studies have shown that a diet rich in MUFAs may result in a wide range of health benefits such as an improvement in cholesterol levels, and, in turn, prevention of cardiovascular disorders\(^\text{[15]}\). In particular, high levels of MUFAs (mainly oleic acid), which have health benefits, are important for human nutrition and are among the major components of the Mediterranean diet, playing an important role in the nutritional value of table olives\(^\text{[50, 44, 49]}\).

The major fatty acids in table olives are oleic, palmitic, stearic, linoleic and palmitoleic acids\(^\text{[12, 56]}\). Because table olives are mainly composed of MUFAs, their consumption can prevent and reduce the risk of cardiovascular diseases, regulate cholesterol levels, stimulate transcription of LDL-cholesterol receptor mRNA, and reduce breast cancer risks\(^\text{[60]}\).

### 3.9 Content of arachidic acid (C20:0), behenic acid (C22:0) and lignoceric acid, C24:0 of olive oil samples

Arachidic acid C20:0, also known as eicosanoic acid, is a saturated fatty acid with a 20-carbon chain. It is a minor constituent of virgin olive oil (0-0.6%) according to olive oil standards and olive pomace oils codex standards 33-1981 (adopted in 1981. revision: 1989, 2003, 2015. amendment: 2009, 2013). Behenic acid (also known as docosanoic acid) is a saturated fatty acid and a minor constituent of virgin olive oil (0-0.2%). Lignoceric acid, or tetracosanoic acid, C24:0 is also a minor constituent of virgin olive oil (0-0.2%).

The fatty acids (C20:0), C22:0 and C24:0 contents were determined in olive oil samples from different locations under study. Regarding C20:0 content in 2009, results (Table 9) showed that there were no significant differences in the content based on the various geographic regions. In 2008 and 2010, on the other hand, significant differences were obtained with a change in the geographic region: the range of C20:0 in 2008 was determined as 0.32%-0.67% and in 2010 the range was determined as 0.61%-0.87%. The content of C20:0 of the olive oil samples in this study (0.32%-0.87%) is higher than that of the literature value (0-0.6%) in some samples. On the other hand, a study by Poiana and Mincione\(^\text{[60]}\) that studied fatty acid evolution and

---

**Table 7** Oleic acid (sum of C18:1 cis and trans) contents (in mg fatty acid/100 mg olive oil) of olive fruits collected from old olive trees in three years (2008-2010) located in different locations in Palestine (n = 10).

| Lo* | oleic acid | | | |
|-----|------------|---|---|---|
|     | 2008 | 2009 | 2010 |
| 1   | 68.0 | – | 65.8 |
| 2   | 68.4 | 70.7 | 66.5 |
| 3   | 68.1 | – | 65.9 |
| 4   | 67.8 | – | 66.8 |
| 5   | 69.4 | 68.9 | 68.9 |
| 6   | 69.0 | 69.4 | 65.8 |
| 7   | 69.5 | 68.5 | 65.3 |
| 8   | – | 68.4 | 66.7 |
| 9   | – | 68.8 | 65.7 |
| 10  | 68.1 | – | 64.8 |
| 11  | 65.0 | – | 62.1 |
| 12  | 68.5 | – | 64.8 |
| 13  | 68.5 | – | 65.7 |
| 14  | 69.6 | – | 66.0 |
| 15  | 68.0 | – | 63.9 |

* Locations: Sourief (1), Bait Jala (2), Bait Reema (3), Kufr Ein (4), Beit Anan (5), Bediah (6), Kufr Al Diek (7), Zaita (8), Bieta (9), Dier Al Gosoun (10), Saida (11), Bieta (12), Kufr Ra’ai (13), Azzoun (14), Sinieria (15).
Table 8  Linoleic (C18:2), and linolenic (C18:3) acids contents (in mg fatty acid/100 mg olive oil) of olive fruits collected from old olive trees in three years (2008-2010) located in different locations in Palestine (n = 10).

| Lo* | C18:2 |  |  | C18:3 |  |  |
|-----|-------|---|---|-------|---|---|
|     | 2008  | 2009 | 2010 | 2008  | 2009 | 2010 |
| 1   | 12.1  | –    | 11.6 | 0.93  | –    | 0.78 |
| 2   | 11.7  | 9.6  | 11.7 | 0.83  | 0.65 | 0.71 |
| 3   | 11.7  | –    | 12.1 | 0.83  | –    | 0.66 |
| 4   | 12.1  | –    | 11.9 | 0.77  | –    | 0.71 |
| 5   | 10.0  | 10.3 | 11.5 | 0.62  | 0.53 | 0.72 |
| 6   | 10.3  | 9.1  | 12.5 | 0.70  | 0.69 | 0.75 |
| 7   | 9.9   | 10.0 | 11.8 | 0.77  | 0.64 | 0.84 |
| 8   | –     | 10.0 | 11.1 | –     | 0.61 | 0.72 |
| 9   | –     | 10.7 | 11.7 | –     | 0.57 | 0.65 |
| 10  | 10.9  | –    | 12.5 | 0.83  | –    | 0.81 |
| 11  | 12.8  | –    | 14.1 | 0.64  | –    | 0.74 |
| 12  | 10.0  | –    | 11.6 | 0.73  | –    | 0.89 |
| 13  | 10.6  | –    | 12.0 | 0.67  | –    | 0.77 |
| 14  | 9.3   | –    | 11.2 | 0.66  | –    | 0.76 |
| 15  | 11.2  | –    | 12.9 | 0.68  | –    | 0.73 |

* Locations: Sourief (1), Bait Jala (2), Bait Reema (3), Kufr Ein (4), Beit Anan (5), Bediah (6), Kufr Al Diek (7), Zaita (8), Bieta (9), Dier Al Gosoun (10), Saida (11), Berqien (12), Kufr Ra'ai (13), Azzoun (14), Sinieria (15).

Table 9  Arachidic acid (C20:0), and behenic acid (C22:0) contents (in mg fatty acid/100 mg olive oil) of olive fruits collected from old olive trees in three years (2008-2010) located in different locations in Palestine (n = 10).

| Lo* | C20:0 |  |  | C22:0 |  |  |
|-----|-------|---|---|-------|---|---|
|     | 2008  | 2009 | 2010 | 2008  | 2009 | 2010 |
| 1   | 0.34  | –    | 0.67 | 0.23  | –    | 0.02 |
| 2   | 0.32  | 0.59 | 0.69 | 0.18  | 0.15 | 0.24 |
| 3   | 0.38  | –    | 0.66 | 0.23  | –    | 0.03 |
| 4   | 0.32  | –    | 0.68 | 0.23  | –    | 0.02 |
| 5   | 0.57  | 0.51 | 0.63 | 0.15  | 0.14 | 0.03 |
| 6   | 0.64  | 0.53 | 0.68 | 0.17  | 0.13 | 0.03 |
| 7   | 0.64  | 0.58 | 0.87 | 0.18  | 0.14 | 0.02 |
| 8   | –     | 0.54 | 0.68 | –     | 0.14 | 0.02 |
| 9   | –     | 0.56 | 0.61 | –     | 0.13 | 0.02 |
| 10  | 0.67  | –    | 0.72 | 0.18  | –    | 0.03 |
| 11  | 0.57  | –    | 0.67 | 0.15  | –    | 0.03 |
| 12  | 0.62  | –    | 0.73 | 0.17  | –    | 0.03 |
| 13  | 0.63  | –    | 0.69 | 0.17  | –    | 0.03 |
| 14  | 0.61  | –    | 0.70 | 0.16  | –    | 0.02 |
| 15  | 0.60  | –    | 0.70 | 0.16  | –    | 0.02 |

* Locations: Sourief (1), Bait Jala (2), Bait Reema (3), Kufr Ein (4), Beit Anan (5), Bediah (6), Kufr Al Diek (7), Zaita (8), Bieta (9), Dier Al Gosoun (10), Saida (11), Berqien (12), Kufr Ra'ai (13), Azzoun (14), Sinieria (15).
composition in olive oil extracted from different olive cultivars grown in the Calabrian area found the content of C20:0 ranged from 0.02-0.4.

Concerning C22:0 content, results (Table 9) showed that there was no significant difference in content between the various locations in 2010. While in 2008 and 2009, significant differences in the concentration were observed among the different geographic locations under investigation with ranges of 0.15-0.23 for 2008 and 0.13-0.15 for 2009. The content of C22:0 of the olive oil samples in this study (0.019-0.23) is higher than that of the literature value (0-0.2) in some samples. On the other hand, a study by Poiana and Mincione found the content of C22:0 ranged from 0.01-0.23.

Table 10 shows the concentration of C24:0 in the olive oil samples investigated in this study. The results showed that the concentration was not significantly different among the various geographic locations in both 2008 and 2010, while in 2009 significant differences were observed among the locations with a range of 0.073-0.084. The range of C24:0 in olive oil samples in this study (0.043-0.12) is in agreement with the literature values according to the standard for olive oil and the olive pomace oils codex stan 33-1981. This is also in agreement with the study of Poiana and Mincione where they found the content of C24:0 ranged from 0.01-0.14.

3.10 Comparison of saturated fatty acids and unsaturated (mono- and poly-unsaturated) fatty acids content

It is interesting to compare saturated fatty acids content with mono- and poly-unsaturated fatty acids in olive oil (Tables 11 and 12). Saturated fatty acids (SAFA) as well as mono- and poly-unsaturated fatty acids were found to be significantly different among the various geographic regions in this study. The highest value of SAFA was found in Sinieria in 2010 (19.3) while the lowest value (17.1) was found in Bait Jala in 2008. MUFA content ranged from 63.0% (found in 2010 in Saida) to 71.4% (found in Bait Jala in 2009). Concerning PUFA, the range was identified from 9.8% (found in 2009 in Bediah) to 14.9% (found in Saida in 2010).

From these results, it is evident that the MUFA content

| Table 10 | Lignoceric acid, C24:0 contents (in mg fatty acid/100 mg olive oil) of olive fruits collected from old olive trees in three years (2008-2010) located in different locations in Palestine (n = 10). |
| --- | --- | --- |
| Location | 2008 | 2009 | 2010 |
| 1 | 0.06 | - | 0.05 |
| 2 | 0.08 | 0.07 | 0.05 |
| 3 | 0.05 | - | 0.05 |
| 4 | 0.08 | - | 0.04 |
| 5 | 0.07 | 0.07 | 0.04 |
| 6 | 0.08 | 0.09 | 0.08 |
| 7 | 0.08 | 0.09 | 0.12 |
| 8 | - | 0.08 | 0.05 |
| 9 | - | 0.07 | 0.08 |
| 10 | 0.08 | - | 0.05 |
| 11 | 0.07 | - | 0.05 |
| 12 | 0.09 | - | 0.06 |
| 13 | 0.08 | - | 0.05 |
| 14 | 0.08 | - | 0.06 |
| 15 | 0.08 | - | 0.08 |

* Locations: Sourief (1), Bait Jala (2), Bait Reema (3), Kufr Ein (4), Beit Anan (5), Bediah (6), Kufr Al Diek (7), Zaita (8), Bieta (9), Dier Al Gosoun (10), Saida (11), Berqien (12), Kufr Ra’ai (13), Azzoun (14), Sinieria (15).

| Table 11 | Saturated fatty acids contents (in mg fatty acid/100 mg olive oil) of olive fruits collected from old olive trees in three years (2008-2010) located in different locations in Palestine (n = 10). |
| --- | --- | --- |
| Lo* | SAFA | 2008 | 2009 | 2010 |
| 1 | 17.3 | 17.3 | 17.3 |
| 2 | 17.1 | 17.1 | 17.1 |
| 3 | 17.6 | 17.6 | 17.6 |
| 4 | 17.4 | 17.4 | 17.4 |
| 5 | 17.7 | 17.7 | 17.7 |
| 6 | 17.6 | 17.6 | 17.6 |
| 7 | 17.3 | 17.3 | 17.3 |
| 8 | - | - | - |
| 9 | - | - | - |
| 10 | 17.8 | 17.8 | 17.8 |
| 11 | 19.3 | 19.3 | 19.3 |
| 12 | 18.3 | 18.3 | 18.3 |
| 13 | 18.5 | 18.5 | 18.5 |
| 14 | 18.3 | 18.3 | 18.3 |
| 15 | 17.8 | 17.8 | 17.8 |

* Locations: Sourief (1), Bait Jala (2), Bait Reema (3), Kufr Ein (4), Beit Anan (5), Bediah (6), Kufr Al Diek (7), Zaita (8), Bieta (9), Dier Al Gosoun (10), Saida (11), Berqien (12), Kufr Ra’ai (13), Azzoun (14), Sinieria (15).
oleic and palmitoleic is higher than PUFA (linoleic and linolenic) and SAFA. Monounsaturated oleic acid is distinctly predominant, followed by saturated palmitic acid and polyunsaturated linoleic acid.

Interest has increased in olive varieties with higher oil content (OC), improved fatty acid composition, mainly high monounsaturated fatty acids (MUFAs) and a high content of phenolic compounds due to its stability and health benefits. While OC is associated with oil quantity and olive growing profitability, proportions of the different fatty acids and phenolic compounds are associated with oil quality. For example, a high MUFA percentage, mainly oleic acid, is a primitive factor in determining the nutritional value of the oil as it reduces the risk of atherosclerosis and protects against different cancers. In addition, fatty acid composition influences the stability of the oil through the contribution of polyunsaturated fatty acids (PUFAs) to oil rancidity.

3.11 Pooled results from the different years

Table 13 shows mean values, standard deviations (SD), minimum values, and maximum values of variables determining oil quality (polyphenols, acidity and peroxide value) and different fatty acids of old olive trees in various locations in Palestine (pooled data in 2008 and 2009). While Table 14 shows the same parameters for the year 2010 as well as pooled data for the three years of the study.

As obvious from this table, the average polyphenolic content of the pooled data in 2008, 2009, and 2010 is 386, 458.9, and 327.3 mg/kg, respectively, with a pooled average of 366.0 mg/kg for the three years. There is also a high standard deviation (166.7) indicating a wide range of polyphenolic content among the samples in various locations in the West Bank. The same was obtained for the other two parameters determining oil quality (percent acidity and peroxide value see Tables 13 and 14).

The pooled mean of palmitic acid percentage C16:0 was found to be 13.30, 13.41, and 13.30 for the years 2008, 2009, and 2010, respectively with a pooled value of 13.31 for the three years indicating comparable content. The same was conducted for the other fatty acids as shown in Tables 13 and 14.

3.12 Ratio indicators for olive oil quality

It is interesting to find the sum ratio of unsaturated fatty acids (mono and poly) to the sum of saturated fatty acids (USFA/SFA) which was found as 4.54, 4.47, 4.33 for the pooled data of 2008, 2009, and 2010, respectively with a
Table 13  Mean values, standard deviations, minimum values, and maximum values of variable determining oil quality (polyphenols (mg/kg oil), acidity (%) and peroxide value (meq. O₂/Kg)) and different fatty acids (mg fatty acid per 100 mg oil) of old olive trees located in different locations in Palestine. Pooled data in 2008 and 2009.

| Variable     | 2008         | 2009         |
|--------------|--------------|--------------|
|              | Mean | SD  | Minimum | Maximum | Mean | SD  | Minimum | Maximum |
| Polyphenols  | 386.6 | 166.6 | 125.0     | 978.0   | 458.9 | 158.8 | 207.5     | 763.9   |
| Acidity      | 0.25  | 0.13  | 0.10      | 1.05    | 0.37  | 0.18  | 0.11      | 1.29    |
| Peroxide     | 5.78  | 2.65  | 2.26      | 13.13   | 6.63  | 2.21  | 2.94      | 14.95   |
| C16:0        | 13.3  | 1.44  | 9.79      | 18.62   | 13.41 | 1.26  | 11.56     | 15.92   |
| C16:1 trans  | 0.14  | 0.11  | 0.07      | 0.70    | 0.09  | 0.016 | 0.07      | 0.16    |
| C16:1 cis    | 0.64  | 0.315 | 0.28      | 1.46    | 0.56  | 0.15  | 0.38      | 1.06    |
| C18:0        | 3.69  | 0.96  | 2.02      | 4.94    | 3.78  | 0.42  | 3.03      | 4.42    |
| C18:1 cis    | 66.67 | 2.15  | 57.32     | 71.64   | 67.41 | 1.79  | 64.30     | 70.57   |
| C18:1 trans  | 1.85  | 0.74  | 1.04      | 4.48    | 1.68  | 0.28  | 1.23      | 2.20    |
| C18:2        | 10.85 | 1.62  | 7.99      | 18.30   | 10.12 | 1.11  | 7.92      | 12.04   |
| C18:3        | 0.74  | 0.17  | 0.46      | 1.77    | 0.60  | 0.08  | 0.45      | 0.77    |
| C20:0        | 0.54  | 0.14  | 0.18      | 0.77    | 0.55  | 0.05  | 0.48      | 0.66    |
| C22:0        | 0.18  | 0.05  | 0.02      | 0.29    | 0.14  | 0.02  | 0.11      | 0.18    |
| C24:0        | 0.08  | 0.03  | 0.03      | 0.24    | 0.08  | 0.01  | 0.06      | 0.11    |
| C16:1 cis+trans | 0.78 | 0.32  | 0.42      | 1.57    | 0.66  | 0.14  | 0.49      | 1.14    |
| C18:1 cis+trans | 68.52 | 1.80  | 59.08     | 73.27   | 69.08 | 1.60  | 66.33     | 72.07   |
| SAFA         | 17.79 | 1.10  | 14.63     | 23.72   | 17.97 | 1.05  | 16.44     | 20.73   |
| MUFA         | 69.20 | 1.68  | 60.17     | 73.88   | 69.74 | 1.51  | 67.10     | 72.70   |
| PUFA         | 11.59 | 1.66  | 8.56      | 18.90   | 10.72 | 1.13  | 8.63      | 12.82   |

pooled value of 4.43 for the three years, indicating comparable ratio. Another ratio was calculated between the sum of monounsaturated fatty acids to the sum of polyunsaturated fatty acids (MUFA/PUFA) which was determined as 5.97, 6.50, and 5.19, for the pooled data of 2008, 2009, and 2010, respectively with a pooled value of 5.63 for the three years. The ratio was also calculated between the oleic to linoleic fatty acids (C18:1/C18:2) which was found to make up 6.14, 6.66, and 5.35 of the pooled data of 2008, 2009, and 2010, respectively with a pooled value of 5.79 for the three years.

These ratios serve as indicators of the olive oil quality where the quality becomes good as they increase. The ratios also strongly influence olive oil oxidative stability and health benefits\(^\text{(20, 57)}\). On the other hand, lower ratios between PUFA and SFA (PUFA/SFA) are linked to higher stability of olive oils. This ratio (PUFA/SFA) was calculated for the pooled data of 2008, 2009 and 2010 and was found to represent: 0.65, 0.59, and 0.70, respectively with a pooled value of 0.66 for the three years.

The high ratio of MUFA/PUFA and C18:1/C18:2 and the low PUFA/SFA ratio is linked to high oxidative stability and low rancidity of olive oil\(^\text{(43)}\); in combination with other minor compounds, this affects the organoleptic and health properties of olive oil\(^\text{(10, 58, 59)}\).

### 3.13 Pearson correlations

Initially Pearson correlations were calculated to test the relation among quality indicators determining oil quality (polyphenols, acidity and peroxide value) and different fatty acids in each study year separately and when data were pooled. The NOMISS option was used in order to obtain results consistent with subsequent multiple regression studies.

### 3.14 Pearson correlations among quality parameters and fatty acids of olive oil collected in 2008 and 2009 from old olive trees

Pearson correlations among quality parameters and fatty acids of olive oil collected from old olive trees in 2008 (Table 15) reveal that the phenolic compounds content (PP) correlates positively with the following parameters: C16:0, C18:1 trans, C18:2, C20:0, palmitoleic (C16:1), and PUFA, while it negatively correlates with C18:0 and C18:1 cis. Acidity is positively correlated with C18:0, and C20:0, but it is negatively correlated with C16:1.
cis, C22:0, and palmitoleic acid. Peroxide value has positive correlation with C16:1 cis, C18:1 trans, C18:3, and palmitoleic acid, and has negative correlation with C18:0. C16:0 is positively correlated with C16:1 cis, C18:1 trans, C18:2, palmitoleic acid, SAFA, and PUFA, but it negatively correlated with C18:0, C18:1 cis, C18:3, C20:0, and oleic acid. C16:1 trans is correlated positively with C18:3 and palmitoleic acid but it negatively correlated with C16:0. C16:1 cis is positively correlated with C18:1 trans, C18:2, C22:0, palmitoleic acid, and PUFA, but it correlated negatively with C18:0, C18:1 cis, C20:0, oleic acid, and MUFA. C18:0 is positively correlated with C18:1 cis, C20:0, oleic acid, and MUFA. C18:0 is found to be positively correlated with C18:1 cis, C20:0, C24:0, and oleic acid, while it is correlated negatively with C18:1 trans, C18:2, C22:0, palmitoleic acid, and PUFA. C18:1 cis is correlated positively with C20:0, oleic acid and MUFA, while it negatively correlated with C18:1 trans, C18:2, C22:0, palmitoleic acid, SAFA, and PUFA. C18:1 trans is positively correlated with C18:2, C22:0, palmitoleic acid, and PUFA, but it negatively correlated with C20:0, and oleic acid. C18:2 is correlated positively with C20:0, palmitoleic acid, and PUFA, while its correlation with C20:0, oleic acid, and MUFA is negative. C18:3 correlated positively with MUFA and PUFA and is negatively correlated with SAFA. C20:0 is correlated positively with C24:0, oleic acid, and MUFA, but it negatively correlated with C22:0, palmitoleic, and PUFA. C22:0 is correlated positively with palmitoleic acid and PUFA, and negatively correlated with SAFA. C24:0 has no correlation with any studied parameter. Palmitoleic acid has positive correlation with PUFA and negative correlation with oleic acid and MUFA. Oleic acid correlated positively with MUFA and negatively with SAFA and PUFA. SAFA has negative correlation with MUFA while MUFA has negative correlation with PUFA.

Pearson correlations among quality parameters and fatty acids of olive oil collected from old olive trees in 2009 (Table 15 diagonal above) show that peroxide value is positively correlated with acidity. C16:1 trans is negatively correlated with C16:0, while C16:1 cis is positively correlated, the later and is negatively correlated with C16:1 trans. C18:0 is positively correlated with both trans and cis versions of the C16:1 fatty acid, while it negatively correlated with C16:0. C18:1 cis is positively correlated with C16:1 trans and C18:0 and is negatively correlated with C16:0 and C16:1 cis. C18:2 is negatively correlated with both

### Table 14
Mean values, standard deviations, minimum values, and maximum values of variable determining oil quality (polyphenols (mg/kg oil), acidity (%) and peroxide value (meq. O2/Kg)) and different fatty acids (mg fatty acid per 100 mg oil) of old olive trees located in different locations in Palestine. Pooled data in 2010 and pooled data of the three years of the study.

| Variable | 2010 | Pooled |
|----------|------|--------|
|          | Mean | SD    | Minimum | Maximum | Mean | SD    | Minimum | Maximum |
| PP       | 327.4 | 157.5 | 103.04 | 747.7   | 366.0 | 166.7 | 103.0 | 978.0 |
| Acidity  | 0.42  | 0.30  | 0.10   | 1.91    | 0.35  | 0.25  | 0.10  | 1.91   |
| Peroxide | 5.79  | 2.82  | 2.49   | 17.21   | 5.89  | 2.69  | 2.26  | 17.21  |
| C16:0    | 13.30 | 1.73  | 10.36  | 18.30   | 13.31 | 1.57  | 9.79  | 18.62  |
| C16:1 trans | 0.10 | 0.02  | 0.00   | 0.15    | 0.12  | 0.07  | 0.00  | 0.70   |
| C16:1 cis | 0.56  | 0.18  | 0.31   | 1.53    | 0.59  | 0.24  | 0.28  | 1.53   |
| C18:0    | 4.17  | 0.50  | 2.18   | 4.91    | 3.94  | 0.74  | 2.02  | 4.94   |
| C18:1 cis | 64.43 | 3.34  | 55.99  | 70.99   | 65.68 | 3.02  | 55.99 | 71.64  |
| C18:1 trans | 1.24 | 3.34  | 0.00   | 3.47    | 1.54  | 0.77  | 0.00  | 4.48   |
| C18:2    | 12.04 | 1.76  | 8.21   | 17.26   | 11.33 | 1.80  | 7.92  | 18.30  |
| C18:3    | 0.75  | 0.12  | 0.53   | 1.10    | 0.73  | 0.14  | 0.45  | 1.77   |
| C20:0    | 0.70  | 0.13  | 0.43   | 1.10    | 0.62  | 0.15  | 0.18  | 1.10   |
| C22:0    | 0.03  | 0.01  | 0.0    | 0.06    | 0.10  | 0.08  | 0.0   | 0.29   |
| C24:0    | 0.06  | 0.07  | 0.03   | 0.81    | 0.07  | 0.05  | 0.03  | 0.81   |
| C16:1 cis+trans | 0.66 | 0.17  | 0.44   | 1.61    | 0.71  | 0.25  | 0.42  | 1.61   |
| C18:1 cis+trans | 65.68 | 2.81  | 58.33  | 70.99   | 67.21 | 2.78  | 58.33 | 73.27  |
| SAFA     | 18.25 | 1.46  | 15.67  | 22.54   | 18.03 | 1.30  | 14.63 | 23.72  |
| MUFA     | 66.34 | 2.69  | 59.23  | 71.44   | 67.9  | 2.71  | 59.23 | 73.88  |
| PUFA     | 12.78 | 1.78  | 8.81   | 18.16   | 12.06 | 1.83  | 8.56  | 18.90  |
Table 15  Pearson coefficient among variable determining oil quality (polyphenols, acidity and peroxide value) and different fatty acids of old olive trees located in different locations in Palestine. Pooled data in 2008 bellow diagonal and for 2009 above diagonal.

|        | PP  | Ac  | Per | C16:0 | C16:1 cis | C16:1 trans | C18:0 | C18:1 cis | C18:1 trans | C18:2 | C18:3 | C20:0 | C22:0 | C24:0 | Palmitoleic | oleic | SAFA | MUFA | PUFA |
|--------|-----|-----|-----|-------|-----------|-------------|-------|-----------|-------------|-------|-------|-------|-------|-------|-------------|-------|------|------|------|
| PP     | -   |     |     |       |           |             |       |           |             |       |       |       |       |       |              |       |      |      |      |
| Ac     |     | -   |     |       |           |             |       |           |             |       |       |       |       |       |              |       |      |      |      |
| Per    |     |     | -   |       |           |             |       |           |             |       |       |       |       |       |              |       |      |      |      |
| C16:0  | 0.27* | -   |     | -0.70*** | 0.91*** | -0.69** | 0.87*** | 0.91*** | 0.93*** | 0.48** | 0.90*** | -0.75*** | 0.93*** | 0.71*** |         |      |      |      |      |
| C16:1 cis | -0.22** | 0.21* | 0.74*** | -0.10 | 0.54** | -0.64*** | 0.90*** | -0.57*** | -0.41* | 0.90*** | -0.76*** | 0.85*** | -0.52** |         |      |      |      |      |
| C16:1 trans | -0.20** | 0.20* | -0.22* | -0.69*** | -0.50* | 0.79*** | -0.70*** | -0.61*** | 0.42* | 0.39* |         |         |         |         |      |      |      |      |
| C18:0  | -0.20** | 0.20* | -0.22* | -0.68*** | -0.50* | 0.79*** | -0.70*** | -0.61*** | 0.42* | 0.39* |         |         |         |         |      |      |      |      |
| C18:1 cis | -0.23* | 0.20* | 0.64*** | 0.85*** | 0.37*** | -0.50*** | 0.84*** | -0.61*** | -0.56*** |         |         |         |         |         |      |      |      |      |
| C18:1 trans | 0.23* | 0.20* | 0.64*** | 0.85*** | 0.37*** | -0.50*** | 0.84*** | -0.61*** | -0.56*** |         |         |         |         |         |      |      |      |      |
| C18:2  | 0.21* | 0.20* | 0.64*** | 0.85*** | 0.37*** | -0.50*** | 0.84*** | -0.61*** | -0.56*** |         |         |         |         |         |      |      |      |      |
| C18:3  | 0.21* | 0.20* | 0.64*** | 0.85*** | 0.37*** | -0.50*** | 0.84*** | -0.61*** | -0.56*** |         |         |         |         |         |      |      |      |      |
| C20:0  | 0.26** | 0.20* | -0.69*** | -0.50* | 0.79*** | -0.70*** | -0.61*** | 0.42* | 0.39* |         |         |         |         |         |      |      |      |      |
| C22:0  | -0.20** | 0.20* | 0.64*** | 0.85*** | 0.37*** | -0.50*** | 0.84*** | -0.61*** | -0.56*** |         |         |         |         |         |      |      |      |      |
| C24:0  | 0.22** | 0.20* | 0.64*** | 0.85*** | 0.37*** | -0.50*** | 0.84*** | -0.61*** | -0.56*** |         |         |         |         |         |      |      |      |      |
| Palmitoleic | 0.21* | 0.20* | 0.64*** | 0.85*** | 0.37*** | -0.50*** | 0.84*** | -0.61*** | -0.56*** |         |         |         |         |         |      |      |      |      |
| oleic  | -0.62** | 0.21* | 0.64*** | 0.85*** | 0.37*** | -0.50*** | 0.84*** | -0.61*** | -0.56*** |         |         |         |         |         |      |      |      |      |
| SAFA   | 0.67*** | -0.69*** | -0.49*** | -0.49*** | -0.49*** | -0.49*** | -0.49*** | -0.49*** | -0.49*** |         |         |         |         |         |      |      |      |      |
| MUFA   | 0.69*** | -0.69*** | -0.49*** | -0.49*** | -0.49*** | -0.49*** | -0.49*** | -0.49*** | -0.49*** |         |         |         |         |         |      |      |      |      |
| PUFA   | 0.19* | 0.20* | 0.64*** | 0.85*** | 0.37*** | -0.50*** | 0.84*** | -0.61*** | -0.56*** |         |         |         |         |         |      |      |      |      |

*indicate significant at $p < 0.05$, **indicate significant at $p < 0.01$, ***indicate significant at $p < 0.001$, n = 133 and 35 in 2008 and 2009 respectively
Table 16  Pearson coefficient among variable determining oil quality (polyphenols, acidity and peroxide value) and different fatty acids of old olive trees located in different locations in Palestine. Pooled data in 2010 below diagonal and for all years above diagonal.

|        | PP       | Ac | Per | C16:0 | C16:1 (trans) | C16:1 (cis) | C16:0 | C18:1 (trans) | C18:1 (cis) | C18:2 | C18:3 | C20:0 | C22:0 | C24:0 | Palmitoleic | oleic | SAFA | MUFA | PUFA |
|--------|----------|----|-----|-------|--------------|-------------|-------|---------------|-------------|-------|-------|-------|-------|-------|--------------|-------|------|------|------|
| PP     |          | -  | 0.14*| 0.14* | -0.46***     | -0.14*      | 0.14* | -0.50***      | -0.14*      | 0.14* | 0.22*** | 0.26*** | 0.19** | 0.14* | -0.61***    | 0.32** |     |      |      |
| Ac     |          | -  | 0.14*|       |              |             |       |               |             |       |       |       |       |       |              |       |      |      |      |
| Per    | -0.34*** | 0.52*** | -  |       |             |             |       |               |             |       |       |       |       |       |              |       |      |      |      |
| C16:0  | -0.34*** | 0.19* | 0.21*| -0.73*** | -0.14*      | 0.13*      | 0.12* |               |             |       |       |       |       |       |              |       |      |      |      |
| C16:1 (trans) | -0.34*** | 0.19* | 0.21*|       | -0.14*      | 0.76***    | -0.56*** | 0.22***      | 0.21***     | 0.22*** | -0.37*** | -0.26*** | 0.19** | 0.14* | -0.61***    | 0.32** |     |      |      |
| C16:1 (cis) | -0.34*** | 0.19* | 0.21*|       | -0.14*      | 0.76***    | -0.56*** | 0.22***      | 0.21***     | 0.22*** | -0.37*** | -0.26*** | 0.19** | 0.14* | -0.61***    | 0.32** |     |      |      |
| C18:0  | -0.31*** | 0.40*** | -  |       |             | -0.73***   | 0.78*** | 0.29***      | 0.27***     | 0.28*** | 0.26*** | 0.24*** | 0.28*** | 0.26*** |              |       |      |      |      |
| C18:1 (trans) | -0.31*** | 0.40*** | -  |       |             | -0.73***   | 0.78*** | 0.29***      | 0.27***     | 0.28*** | 0.26*** | 0.24*** | 0.28*** | 0.26*** |              |       |      |      |      |
| C18:1 (cis) | -0.31*** | 0.40*** | -  |       |             | -0.73***   | 0.78*** | 0.29***      | 0.27***     | 0.28*** | 0.26*** | 0.24*** | 0.28*** | 0.26*** |              |       |      |      |      |
| C18:2  | -0.19*   | 0.2*  |     |       |             | -0.82***   | 0.42*** | -0.20***     | -0.20***    |       |       |       |       |       |              |       |      |      |      |
| C18:3  | -0.19*   | 0.2*  |     |       |             | -0.82***   | 0.42*** | -0.20***     | -0.20***    |       |       |       |       |       |              |       |      |      |      |
| C20:0  | -0.18**  |       |     |       |             | -0.17*     | -0.15*   | 0.15*        | -0.18***    | 0.27*** |       |       |       |       |              |       |      |      |      |
| C22:0  | -0.18**  |       |     |       |             | -0.17*     | -0.15*   | 0.15*        | -0.18***    | 0.27*** |       |       |       |       |              |       |      |      |      |
| Palmitoleic | 0.87*** |       |     |       |             | -0.54***   | 0.90*** | -0.62***     | -0.62***    | -0.62*** | 0.41*** | 0.61*** | 0.62*** | 0.61*** | -0.54***  | 0.39*** | 0.29*** |       |      |
| oleic  | -0.79*** |       |     |       |             | -0.49***   | 0.70*** | 0.39***      | 0.39***     | 0.39*** | -0.36*** | -0.36*** | -0.36*** | -0.36*** |              |       |      |      |      |
| SAFA   | 0.95***  |       |     |       |             | 0.60***    | 0.69*** | 0.49***      | 0.49***     | 0.49*** | -0.36*** | -0.36*** | -0.36*** | -0.36*** |              |       |      |      |      |
| MUFA   | -0.77*** |       |     |       |             | -0.47***   | 0.67*** | 0.29***      | 0.29***     | 0.29*** | -0.36*** | -0.36*** | -0.36*** | -0.36*** |              |       |      |      |      |
| PUFA   | -0.23**  | 0.17* |     |       |             | 0.40***    | 0.40*** | 0.99***      | 0.99***     | 0.99*** | 0.19*   | -0.21*   | 0.42*** | 0.46*** | -0.33***  | 0.39*** | 0.28*** |       |      |

*p* indicate significant at *p* < 0.05, **indicate significant at *p* < 0.01, ***indicate significant at *p* < 0.001, *n* = 142 and 290 in 2010 and all years respectively.
C18:0 and C18:1 cis. C18:3 is negatively correlated with C18:1 cis. C20:0 is positively correlated with C16:0, C16:1 trans, C18:0 and C18:3, while it negatively correlated with C16:1 cis and C18:1 trans. C22:0 positively correlated with C16:0, C16:1 trans, C18:0, C18:3, and C20:0, while it is negatively correlated with C16:1 cis and C18:1 trans. C24:0 positively correlated with C18:3, C20:0, and C22:0. Palmitoleic acid positively correlated with C16:0, C16:1 cis, C18:1 trans, and PUFA, but it negatively correlates with C16:1 trans, C18:0, C18:1 cis, C20:0, C22:0, oleic acid, and MUFA. Oleic acid correlates positively with C18:0, C18:1 cis, and MUFA, while it correlates negatively with C16:0, C16:1 cis, C18:1 trans, C18:2, C18:3, palmitoleic, SAFA, and PUFA. SAFA is positively correlated with C16:0, C16:1 cis, and palmitoleic acid, while it negatively correlated with C16:1 trans, C18:1 cis, oleic acid, and MUFA. MUFA correlates positively with C18:0 and C18:1 in addition to oleic acid, while it correlates negatively with C16:0, C16:1 cis, C18:1 trans, C18:2, C18:3, palmitoleic acid, and SAFA. PUFA is positively and highly correlated with C18:3, while it is negatively correlated with C18:1 cis, oleic acid, and MUFA.

3.15 Pearson correlations among quality parameters and fatty acids of olive oil collected in 2010 and in pooled data of all years from old olive trees

Pearson correlations among quality parameters and fatty acids of olive oil collected from old olive trees in 2010 (Table 16 diagonal below) show that phenolic compounds (PP) are only negatively correlated with peroxide value, C16:1 trans, C18:0, C18:2, and C18:3. Acidity has positive correlations with peroxide values, C16:1, C18:2, and total polyunsaturated fatty acids (PUFA), and negatively correlated with C18:3 and C20:0. Peroxide value was slightly negatively correlated with phenolic compounds and tightly positively correlated with acidity and slightly positively correlated with C16:1 trans. The fatty acid C16:0 significantly and highly correlated with most of the tested parameters. It positively correlated with C16:1, C18:1, C18:2, palmitoleic acid, saturated fatty acids (SAFA), and polyunsaturated fatty acids (PUFA). Correlation with C16:1 trans, C18:0, C18:1 cis, C20:0, oleic acid, and monounsaturated fatty acids (MUFA) was significantly negative. The fatty acid C16:1 trans positively correlated with C18:0, C18:1 cis, C18:3, C20:0, oleic acid, and MUFA, while it negatively correlated with C16:1 cis, C18:1 trans, C24:0, palmitoleic acid, and SAFA. C16:1 cis fatty acid positively correlated with C18:1 trans, C18:2, palmitoleic acid, SAFA, and PUFA, while its correlation with C18:0, C18:1 cis, C20:0, oleic, and MUFA was significantly negative. The fatty acid C18:0 was positively correlated with C18:1 cis, C18:3, C20:0, oleic acid, and MUFA, while it had negative correlation with C18:1 trans, palmitoleic acid, and SAFA. C18:1 cis highly positively correlated with MUFA and negatively correlated with its trans version, C18:2, palmitoleic acid, SAFA, and PUFA. C18:2 correlations with palmitoleic acid, SAFA, and PUFA were significantly positive, while that with oleic acid and MUFA were significantly negative. The correlation between C20:0 was slightly positive with C22:0 and negative with palmitoleic acid and PUFA. Palmitoleic acid is negatively correlated with oleic acid and MUFA and positively correlated with SAFA and PUFA. Oleic acid is highly correlated with SAFA and PUFA (+ve), and with MUFA (+ve). SAFA are negatively correlated with MUFA and positively correlated with PUFA. Finally, MUFA is negatively correlated with PUFA.

Pearson correlations among quality parameters and fatty acids of olive oil collected from old olive trees as pooled data in all years of study (Table 16 diagonal above) reveal that, peroxide value is negatively correlated with phenolic compounds. C16:0 only correlated with phenolic compounds in a slightly positive manner. C16:1 trans negatively correlated with C16:1 trans. C16:1 cis positively correlated with C16:0 and negatively correlated with acidity and C16:1 trans. C18:0 slightly positively correlated with acidity and C16:1 trans but negatively correlated with phenolic compounds and C16:0. C18:1 cis is positively correlated with C18:0 and negatively correlated C16:0 and C16:1 cis. C18:1 trans positively correlated with phenolic compounds, C16:0, and C16:1 cis, while it negatively correlated with acidity, C18:0, and C18:1 cis. The fatty acid C18:2 is positively correlated with acidity, C16:0, C16:1 cis, and C18:1 trans, while it is negatively correlated C18:0 and C18:1 cis. C18:3 positively correlated with C16:1 trans and C18:2, while its correlation with phenolic compounds, acidity, and C16:0 is negative. The correlation between C20:0 and C18:0 and C18:3 is positive, while the former is correlated negatively with phenolic compounds, peroxide value, C16:0, and C16:1 trans. The C22:0 fatty acid has positive correlation with phenolic compounds, C16:1 trans, C16:1 cis, and C18:1 trans, while its correlation with acidity C18:0, C18:2, and C20:0. C24:0 was not correlated with any tested parameter. Palmitoleic acid positively correlated with C16:0, C16:1 trans, C16:1 cis, C18:1 trans, C18:2, and C22:0, while it negatively correlated with acidity, C18:0, C18:1 cis and C20:0. Oleic acid has positive correlation with phenolic compounds, C18:1 cis, and C22:0, while it shows negative correlation with acidity, C16:0, C16:1 cis, C18:1 trans, C18:2, C20:0, and palmitoleic acid. SAFA is positively correlated with C16:0, C16:1 cis, C18:1 cis, C18:1 trans, C18:2, and palmitoleic acid, while it negatively correlated with C18:3, C22:0, and oleic acid. MUFA is correlated positively with phenolic compounds, C18:1 cis, C22:0, and oleic acid, while it has negative correlation with acidity, C16:0, C16:1 cis, C18:1 trans, C18:2, C20:0, palmitoleic acid, and SAFA. Finally, PUFA is positively correlated with acidity, C16:0, C16:1 cis, C18:1 trans, C18:2, C18:3, palmitoleic acid, and SAFA, while it negatively correlated with...
phenolic compounds, C18:0, C18:1 cis, C22:0, oleic acid, and MUFA.

4 Conclusion

This work outlines some olive oil quality parameters (fatty acid profile, acidity levels, peroxide value, total phenolic content) of old olive trees in Palestine. The fatty acid trends showed characteristics typical of virgin olive oil. Acidity levels and peroxide values were also typical of virgin olive oil. The olive oil samples were rich in polyphenolic compounds reflected by total phenolic content. Oleic, palmitic, stearic, linoleic, and palmitoleic acids are the major fatty acids in the olive oil samples with more monounsaturated (MUFA) than polyunsaturated fatty acids (PUFA). Some correlations between total phenolic content, peroxide value or percentage of acidity and fatty acids were observed. Fatty acid composition varies according to the evaluated geographic region in West Bank although wide ranges of variance were obtained in the collection year.

Author Contributions

The research was designed and conducted by T. Hijawi. Additionally, T. Hijawi analysed data and results and wrote the manuscript.

Acknowledgements

Technical support by Mr. (Eng. Mohammad Humidat) in Al Reef Company is gratefully acknowledged for his help in data collection and for Mr. (Nasser Samara) in Association for Integrated Rural Development for oil sample analysis. Financial support for this study was obtained from (German Research Foundation), through the project (Assessing pheno- and genotypic differentiation of old olive trees in correlation with environmental parameters).

Conflict of Interest Statement

The authors declare there are no conflicts of interest.

References

1) FAO Statistics (online): http://www.fao.org/faostat/en/#data/QC, accessed on 14th January 2021.
2) PCBS-Palestinian Central Bureau of Statistics. First agricultural census in the Palestinian Territory 2010.
3) Soy ergin, S.; Moltay, I.; Genç, C.; Fidan, A.E.; Sutçu, A.R. Nutrient status of olives grown in the Marmara region. Acta Hort. 586, 375-379 (2002).
4) Ministry of Agriculture (MOA) General Directorate of Extension & Rural Development. Olive Oil Fact Sheet, pp. 1-3 (2010).
5) Lodolini, E.M.; Polverigiani, S.; Ali, S.; Qutub, M.M.M.; Arabasi, T.; Pierini, F.; Abed, M.; Neri, D. Oil characteristics of four Palestinian olive varieties. J. Oleo Sci. 66, 435-441 (2017).
6) Lavee, S.; Wodner, M. The effect of yield, harvest time and fruit size on the oil content in fruits of irrigated olive trees (Olea europaea), cvs. Barnea and Manzanillo. Sci. Hortic. 99, 267-277 (2004).
7) Olveras-López, M.J.; Berná, G.; Jurado-Ruiz, E.; López-García de la Serrana, H.; Martín, P. Consumption of extra-virgin olive oil rich in phenolic compounds has beneficial antioxidant in healthy human adults. J. Funct. Foods 10, 475-484 (2014).
8) Tous, J.; Romero, A. Cultivar and location effects in olive oil quality in Catalonia, Spain. Acta Hort. 356, 323-326 (1994).
9) Maestro-Durán, R.; Borja-Padilla, R. La calidad del aceite de oliva en relación con la composición y maduración de la aceituna. Grasas y Aceites 41, 171-178 (1990).
10) European Community Regulation. 1991. Official Journal of European Community, L248, September 5th.
11) European Community Regulation. 2001. Official Journal of European Community, L201, July 26th.
12) Conte, L.S.; Bortolomeazzi, R.; Moret, S.; Pizzale, L.; Vichi, S. Recent acquisitions acquisition analitiche per la valutazione della della qualità, genuinità e stabilità dei grassi alimentari. Riv. Italiana Sost. Grasse 77, 431-438 (2000).
13) Bianci, G. Lipids and phenols in table olives. Eur. J. Lipid Sci. Technol. 105, 229-242 (2003).
14) Aktas, A.B. Chemical characterization of ‘Hurna’ olive grown in Karaburun Peninsula. Izmir Institute of Technology (2013).
15) Boskou, G.; Salta, F.N.; Chrysoptomou, S.; Mylona, A.; Chiou, A. Antioxidant capacity and phenolic profile of table olives from the Greek market. Food Chem. 94, 558-564 (2006).
16) Spagnoli, P.; Parenti, A.; Cardini, D.; Modì, G.; Caselli, S. Characterization of single variety extra virgin olive oils of three cultivars from Tuscany. Riv. Italiana Sost. Grasse 75, 227-233 (1998).
17) De Leonardis, A.; De Felice, M.; Macciola, V. Fatty acid composition of extra virgin olive oils from the lower Ramallah, State of Palestine, pp.1-4 (2011).
Oil Quality of Old Olive Trees in Palestine

J. Oleo Sci.

Molise region. Riv. Italiana Sost. Grasse 73, 321-325 (1996).

Boschelle, O.; Giomo, A.; Conte, L.; Lercker, G. Chemometric applications to the study of correlations between chemical-physical data for characterization of olive cultivars from Trieste gulf. Riv. Italiana Sost. Grasse 71, 57-65 (1994).

Alonso García, M.V.; Aparicio Lopez, R. Characterization of European virgin olive oils using fatty acids. Grasas y Aceites 44, 18-24 (1993).

Tsimidou, M.; Karakostas, K.X. Geographical classification of Greek virgin olive oil by non-parametric multivariate evaluation of fatty acid composition. J. Sci. Food Agric. 62, 253-257 (1993).

Stefanoudaki, E.; Kotsifaki, F.; Koutsafaktis, A. Sensory and chemical profiles of three European olive varieties (Olea europaea L.); An approach for the characterization and authentication of the extracted oils. J. Sci. Food Agric. 80, 381-389 (2000).

Salvador, M.D.; Aranda, F.; Gó mez-Alonso, S.; Fregapane, G. Influence of extraction system, production year and area on Cornicabra virgin olive oil: A study of five crop seasons. Food Chem. 80, 359-366 (2003).

Loumou, A.; Giourga, C. Olive groves: ‘The life and identity of the Mediterranean’. Agric. Human Values 20, 87-95 (2003).

Ferraj, B.; Teqia, Z.; Susaj, L.; Fasllia, N.; Gjeta, Z.; Vata, N.; Balliu, A. Effects of different soil management practices on production and quality of olive groves in Southern Albania. J. Food Agric. Environ. 9, 430-433 (2011).

Ryan, D.; Antolovich, M.; Prenzler, P.; Robards, K.; Lavee, S. Biotransformations of olive phenolic compounds in olive. L. Sci. Hortic. 92, 147-176 (2002).

Houshia, O.J.; Qutit, A.; Zaid, O.; Shqair, H.; Zaid, M. Determination of Total Polyphenolic Antioxidants Contents in West-Bank Olive Oil. J. Nat. Sci. Res. 4, 2224-3186 (2014).

Dagdelen, A. Identifying antioxidant and antimicrobial activities of the phenolic extracts and mineral contents of virgin olive oils (Olea europaea L. cv. Edincik Su) from different regions in Turkey. Journal of Chemistry 5, 1-11 (2016).

Eid, M.M.; El-Sayed, M. Characterization of some new olive oil genotypes growing in El-khatatba zone – Egypt. Egyptian Journal of Agricultural Research 91 (2013).

Dabbou, S.; Brahmi, F.; Dabbou, S.; Issaoui, M.; Sifi, S.; Hammami, M. Antioxidant capacity of Tunisian virgin olive oils from different olive cultivars. African Journal of Food Science and Technology 2, 92-97 (2011).

Abbadi, J.; Afaneh, I.; Ayyad, Z.; Al-Rimawi, F.; Sultan, W.; Kanaan, K. Evaluation of the effect of packing materials and storage temperatures on quality degradation of extra virgin olive oil from olives grown in Palestine. Am. J. Food Technol. 2, 162-174 (2014).

Afaneh, I.A.; Abbadi, J.; Ayyad, Z.; Sultan, W.; Kanaan, K. Evaluation of selected quality degradation indices for Palestinian extra virgin olive oil bottled in different packaging materials upon storage under different lighting conditions. J. Food Sci. Eng. 3, 267-283, (2013).

Baldioli, M.; Servili, M.; Perretti, G.; Montedoro, G.F. Antioxidant activity of tocopherols and phenolic compounds of virgin olive oil. J. Am. Oil Chem. Soc. 73, 1589-1593 (1996).

Cortesi, N.; Azzolini, M.; Rovellini, P.; Fedeli, E. Minor polar components of virgin olive oils: A hypothetical structure by LC-MS. Riv. Ital. Sos. Gra. 72, 241-251 (1995).

Visioli, F.; Galli, C. Olive oil phenols and their potential effects on human health. J. Agric. Food Chem. 46, 4292-4296 (1998).

European Union Commission. Regulation EEC 2568/91 on the characteristics of olive oil and olive-residue oil and on the relevant methods of analysis. Official J. Eur. Commun. 248 (1991).

Velasco, J.; Dobarganes, C. Oxidative stability of virgin olive oil. Eur. J. Lipid Sci. Technol. 104, 661-676 (2002).

Gomez-Alonso, S.; Mancebo-Campos, V.; Salvador, M.D.; Fregapane, G. Evolution of major and minor components and oxidation indices of virgin olive oil during 21 months storage at room temperature. Food Chem. 100, 36-42 (2007).

Garcia-Gonzalez, D.L.; Aparicio-Ruiz, R.; Aparicio, R. Virgin olive oil-chemical implications on quality and health. Eur. J. Lipid Sci. Technol. 110, 1-6 (2003).

Mendes, R.; Pestana, G.; Goncalves, A. The effects of soluble gas stabilisation on the quality of packed sardine fillets (Sardina pilchardus) stored in air, VP and MAP. Int. J. Food Sci. Technol. 43, 2000-2009 (2008).

Matson, F.M.; Grundy, S.M. Comparison of effects of dietary saturated, monounsaturated and polysaturated fatty acids on plasma lipids and lipoproteins in men. J. Lipid Res. 26, 194-202 (1985).

Hammond, E.G.; Fehr, W.R. Improving the fatty acid composition of soybean oil. J. Am. Oil Chem. Soc. 61, 1713-1716 (1984).

Tous, J.; Romero, A. Variedades de Olivo. Barcelona: Fundación ‘La Caixa’ (1993).

Sakouhi, F.; Herchi, W.; Sebei, K.; Ajsalon, S.; Kallel, H. Accumulation of total lipids, fatty acids and triacylglycerols in developing fruits of Olea europaea L. Sci. Hortic. 132, 7-11 (2011).

Duffy, P.E.; Quinn, S.M.; Roche, H.M.; Evans, P. Synthesis of trans-vaccenic acid and cis-9-trans-11-conjugated linoleic acid. Tetrahedron 62, 4838-4843

J. Oleo Sci.
El Riachy, M.; Hamade, A.; Ayoub, R.; Dandachi, F.; Chalak, L. Oil content, fatty acid and phenolic profiles of some olive varieties growing in Lebanon. Front. Nutr. 6, 94 (2019).

León, L.; Uceda, M.; Jiménez, A.; Martín, L.M.; Rallo, L. Variability of fatty acid composition in olive (Olea europaea L.) Progenies. Spanish Journal of Agricultural Research 2, 353-359 (2004).

Poiana, M.; Mincione, A. Fatty acids evolution and composition of olive oils extracted from different olive cultivars grown in Calabrian area. Grasas y Aceites 282, 282-290 (2004).

Charoenprasert, S.; Mitchell, A. Factors influencing phenolic compounds in table olives (Olea europaea). J. Agric. Food Chem. 60, 7081-7095 (2012).

Aparicio, M.; Cano, N.; Chauveau, P.; Azar, R.; Canaud, B.; Flory, A. Nutritional status of haemodialysis patients: A French national cooperative study. French Study Group for Nutrition in Dialysis. Nephrol. Dial. Transplant. 14, 1679-1686 (1999).

Frankel, E.N. Nutritional and biological properties of extra virgin olive oil. J. Agric. Food Chem. 59, 785-792 (2011).

Ollivier, D.; Artaud, J.; Pinatel, C.; Durbec, J.P.; Guérère, M. Triacylglycerol and fatty acid compositions of French virgin olive oils. Characterization by chemometrics. J. Agric. Food Chem. 51, 5723-5731 (2003).

Biyikli, K. Determination of the purity grades of Turkish olive oil. Ankara University Institute of Natural and Applied Sciences, Graduate Thesis, Ankara (2009).

Diraman, H.; Sobuçovali, S.; Ve Yüksel, F. Oxidative stability and fatty acid components in Gemlik varieties of natural olive oil produced in various regions. Gida 40, 93-100 (2015).

Anon, International Olive Oil Council (2007).

Sakouhi, F.; Harrabi, S.; Absalon, C.; Sbei, K.; Boukhchina, S. α-Tocopherol and fatty acids contents of some Tunisian table olives (Olea europaea L.): Changes in their composition during ripening and processing. Food Chem. 108, 833-839 (2008).

Mensink, R.P.; Katan, M.B. Effect of dietary fatty acids on serum lipid and lipoproteins. A meta-analysis of 27 trials. Arterioscler Thromb. 12, 911-919 (1992).

Boskou, D. Olive Oil Chemistry and Technology. AOCS Press, Champaign, IL (1996).

Ebaid, R.; Abu-Qaoud, H. Morphological and biochemical characterization of three olive (Olea europaea L.) Cultivars in Palestine. Jordan Journal of Agricultural Sciences 10, 130-143 (2014).

CC BY 4.0 (Attribution 4.0 International). This license allows users to share and adapt an article, even commercially, as long as appropriate credit is given. That is, this license lets others copy, distribute, remix, and build upon the Article, even commercially, provided the original source and Authors are credited.