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Effect of Production System (Organic versus Conventional) on Olive Fruit and Oil Yields and Oil Quality Parameters in the Messara Valley, Crete, Greece; Results from a 3-Year Farm Survey

Nikolaos Volakakis [1,2,3,*], Emmanouil Kabourakis [1,*], Apostolos Kiritsakis [4,5], Leonidas Rempelos [3] and Carlo Leifert [3,6,7]

1. Olive and Agroecological Production Systems Laboratory (EOPS), Hellenic Mediterranean University, P.O. Box 1939 Estavromenos, Heraklion, 71004 Crete, Greece
2. Geokomi Plc, P.O. Box 21 Sivas Festos, 70200 Crete, Greece
3. Nafferton Ecological Farming Group, Newcastle University, Newcastle upon Tyne NE1 7RU, UK; leonidas.rempelos@ncl.ac.uk (L.R.); carlo.leifert@gmail.com (C.L.)
4. International Hellenic University, Thermi, 57001 Thessaloniki, Greece; kyritsak@gmail.com
5. International Observatory of Oxidative stress for Health and Agricultural Products, 21 Kar. Diehl Str., 54623 Thessaloniki, Greece
6. SCU Plant Science, Southern Cross University, Military Rd., Lismore, NSW 2480, Australia
7. Department of Nutrition, IMB, University of Oslo, 0372 Oslo, Norway

* Correspondence: nvolakakis@gmail.com (N.V.); ekabourakis@hmu.gr (E.K.)

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Abstract: The demand for organic olive oil has increased rapidly over the last 40 years, but there is limited information on the effects of organic production methods on commercially and nutritionally relevant quality parameters in olive oil. The main objective of this farm survey-based study was therefore to compare fruit and oil yields and important oil quality parameters (including acidity, peroxide value and fatty acid profiles) between organic and conventional farms located in the Messara Plain and foothills. As expected, yields were substantially higher on farms in the Messara Plain compared with those in the foothills which have poorer soil, less access to irrigation water and are the more extensively managed. However, different to the many previous studies (which reported lower yields in organic systems), both fruit and oil yields were not significantly different in organic and conventional production and numerically ~10% higher in organic production. Additionally, olive oil quality was very high, and no substantial effects of production systems and farm location were found. Potential factors (e.g., low olive fly pressure) which may have contributed to the lack of a yield and quality gap between organic and convention production in the Messara region are discussed.

Keywords: acidity; conventional; fatty acid profile; olive oil yield; organic; peroxidase value

1. Introduction

Organic olive oil production has expanded rapidly in Greece and other Mediterranean countries over the last 30 years [1].

The environmental benefits of organic production are widely accepted and rewarded by EU/national government subsidies. Environmental benefits include: (a) reduced pollution of surface and ground water from leaching and/or run-off of mineral N and P fertilisers and chemosynthetic crop protection products [2–6]; (b) increased biodiversity in agricultural eco-systems with respect to bird, invertebrate and non-crop plant populations [6–11]; and (c) reductions in energy use and greenhouse gas emissions [6,12–18]. Although there are very few studies into the environmental benefits of organic olive production; it is assumed that it provides similar benefits [18].

However, the main driver for consumer demand for organic products, including olive oil and table olives, have been consumer perceptions that organic foods have a higher nutritional value and result in health benefits [6,19,20]. However, although there is mounting evidence that organic management improves the nutritional composition/quality in a range of crops (including cereals, vegetables and fruit) [6,21–24], there is limited information for table olives and olive oil [25–29], except for the well-documented problem of organophosphate (OP) pesticide residues (OPs are used for olive fly control) in conventional olive oil [30,31]. Additionally, most previous studies reported no substantial differences in nutritional quality parameters between organic and conventional olive oil [26–29], except for a recent study by López-Yerena et al. [25], which reported significantly higher concentrations of phenolic compounds in organic compared with conventional extra virgin olive oil of the variety Hojiblanca and one study which reported higher oleic acids in organic production [32].

However, olive oil yield and quality are known to be significantly reduced by high levels of olive fly fruit (*Bactrocera oleae*) infestation [29,33] and the inability to use chemosynthetic pesticides for the control of olive fly in organic production is widely assumed to result in higher olive fly infestation and lower oil quality (e.g., higher acidity) in organic production systems [33–35].

In organic production, mass trapping systems are widely used for olive fly control, although some farmers also use kaolin-clay, copper and pesticides permitted under EU-organic regulation such as spinosat for olive fly control [6,28,34–37]. Both mass trapping and permitted crop protection products are thought to be less effective than pesticide-based crop protection especially in areas with higher pest population pressure [28,34–37]. Although there are, to our knowledge, no studies comparing the efficacy of olive fly management in organic and conventional production systems, mass trapping was shown to substantially reduce the need for insecticide applications in conventional production [37–39].

The most important obstacles preventing further increases in demand for organic foods is the higher price of organic products [6,19,20]. Prices for organic table olives, olive oil and other processed olive products are currently between 60 and 100% higher than those of equivalent products from conventional production. This is usually attributed to lower yields and higher costs associated with (1) more expensive inputs (e.g., compost and manure, legume seed and mass trapping systems), (2) quality assurance (to avoid pesticide residues in organic oil it is recommended that trees bordering conventional orchards are not harvested for organic products) and (3) certification/auditing [34,35]. Recent meta-analyses showed that yields are significantly lower in organic compared with conventional crop production systems [40–43], but that there is very limited comparative information on yields and cost structures olive production systems [26,34,35,38,44,45].

The main objective of the study reported here was therefore to compare fruit and olive oil yields, and commercially and nutritionally relevant oil quality parameters in organic and conventional production systems in the Messara region, one of the main areas of commercial olive oil production in Greece.

2. Materials and Methods

2.1. Survey Area

The survey area was the west Messara Plain and the surrounding foothills, an area around Moires in southern Crete, Greece (Figure 1). The survey took place in two growing seasons (2006/2007 and 2007/2008). The first year, four pairs of neighbouring organic and conventionally managed olive orchards were surveyed. Two pairs were located in the foothills, where both organic and conventional orchards are managed more extensively and two in the Messara Plain, where olive orchards are managed intensively. In the plain, there are also many intensively managed conventional vegetable production fields. In the second year of the survey, the number of the orchards was doubled (Table 1).

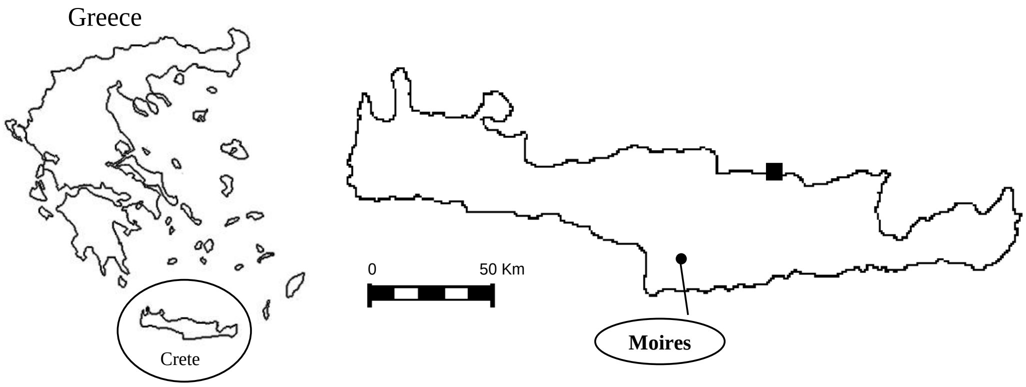

Figure 1. Location of the survey area in Crete, Greece.

Table 1. Number of orchards surveyed for fruit and oil yields (orchards sampled for fruit quality parameters and fatty acid composition).

		Growing Season		
Location of Orchards	**Production System**	**2005/06** [1]	**2006/07**	**2007/08**
Messara Plain	Organic	4 (0)	4 (2)	4 (4)
	Conventional	4 (0)	4 (2)	4 (4)
Foothills	Organic	4 (0)	4 (2)	4 (4)
	Conventional	4 (0)	4 (2)	4 (4)
Total number of orchards surveyed			16 (8)	16 (16)

[1], in the 2005/2006 season only olive fruit and oil yields were assessed.

All orchards included in the survey were olive-oil-producing olive orchards, planted with the cultivar Koroneiki and had a minimum size of 0.5 ha. All organic orchards were certified in accordance with the European Union (EU) organic farming regulations [46].

In conventional orchards, crop protection protocols were based on synthetic chemical herbicides, insecticides and fungicides, although most conventional orchards also used mechanic weed control methods. In organic orchards mechanical weed control, careful pruning, mass trapping for olive fly control and, if required, copper application for the sooty mold and *Bacillus thuringiensis* (Bt) for *Prays oleae* are undertaken.

2.2. Yield Records and Fruit Sampling

Yields were recorded over 3 successive harvest years (2006, 2007 and 2008) in all orchards included in the survey. Yield data were provided by the farmers and were based on weights of harvested olives and oil recorded in the olive oil mills used for processing.

Olive fruit sampling was performed in November in 2006 and 2007. Samples were taken from 10 randomly selected trees in each orchard. Five kg of olive fruits was collected by hand during the harvest. Olive fruits were harvested when 50% of the olive fruit displayed partial or total purple colour; this was equivalent to maturity index 7 for at least 50% of the fruit harvested.

2.3. Fruit Processing, Determination of Water and Oil Content

Olive fruits were processed on the day of sampling. Oil was obtained using a laboratory scale olive mill (Kallis S.A, Athens, Greece) and crushing of olive fruits was carried out using a hammer mill operating at 3000 rpm. A total of 700 g of paste obtained from the hammer mill was malaxed at 50 rpm for 30 min at 28 ± 2 °C. The paste was centrifuged at 1400× *g* for 2 min and the liquid phase was further centrifuged for 10 min at 3500 rpm in a Fisher Scientific Accuspin 3R Centrifuge. The oil layer was carefully recovered and samples were kept in 100 mL dark glass bottles at −20 °C until analysis.

Crushed paste samples were weighted in a tared mash beaker, which had been previously dried and cooled in a desiccator. Samples were kept in an oven at 105 °C until a constant weight was reached and the determined weight loss was recorded as water content. The oil content of fruit was determined per gram of dry weight by using the Soxhlet extraction method [47] and hexane as an extraction solvent.

2.4. Oil Quality Parameters

Assessments of free acidity, peroxide index and specific extinction coefficients K_{232}, K_{270}, K_{262}, K_{268}, K_{274} and DeltaK (ΔK) in olive oil were carried out according to the European Official Methods of Analysis [48].

Acidity. Oil acidity is based on the amount of free fatty acids (FFAs) present in olive oil, is an important sensory quality parameter and is also linked to shelf-life and authenticity of the oil. Olive oil acidity reflects the quality of olives used for olive oil production and is mainly increased before the olive fruit processing in the olive oil mill. This quality parameter is basically used for olive oil categorization and as a marker of olive oil quality. FFA determination methods include both classical (titration) and instrumental methods [49].

Peroxide value. The most common method used for evaluating the extent of oxidation in fats, oils and food lipids is to determine the peroxide value (PV). Peroxides are the primary products of the oxidation which is the main deteriorative process that occurs in lipids and affects their quality adversely, particularly in relation to the off-flavour and rancidity development. High temperature, exposure to visible or diffused light and oxygen, contact with metal surfaces (e.g., copper), physical, disease and pest damage to fruit and delays between harvest and processing time can increase the risk of oxidation of olive oils [50,51].

Specific coefficients of olive oil (K_{232}, K_{270} and ΔK). Upon oxidation, conjugated peroxides (hydroperoxides) are formed as primary oxidation products of olive oil and these give rise to absorption peaks at 232 nm in the ultraviolet (UV) region [52]. Hydroperoxides are easily decomposed to secondary oxidation products (aldehydes and ketones) which absorb at 270 nm and around 270 nm. The absorbance values at 262 nm, 268 nm, and 274 nm were used for the determination of ΔK ($\Delta K = K_{268} - ((K_{262} + K_{274})/2)$ and further to categorize the oxidation level of olive oil [52].

Extra virgin olive oil is the category of olive oil with the highest sensory quality. Olive oil is classified as having a free acidity, expressed as free oleic acid, of no more than 0.8 g per 100 g and a peroxide value of lower than 20, a K_{232} of lower than 2.50, a K_{268} or K_{270} of lower than 0.22 and ΔK lower than 0.01 [48].

2.5. Fatty Acid Profile Analyses

A standard gas chromatography (GC) method was used for fatty acid profiling. Olive oil samples were kept at −20 °C prior to analysis. Samples were thawed at room temperature and 0.05 g of each sample was transferred into a screw-topped test tube with Teflon seals. Samples were analysed in duplicate, adding either 0.5 mL C 17:0 in toluene solution (0.75 mg/mL) or 0.5 mL C21:0 in toluene solution (1.25 mg/mL) as internal standards. Half a mL of toluene and 1.7 mL of methanol:toluene (4:1 v/v) (which were used for the extraction of the lipid prior to the GC analysis) were added to the tube and then vortexed. The methylation of the extracted lipid was achieved by the addition of 0.25 mL of acetyl chloride. Samples were incubated at 100 °C for one hour in a dry hot-block Dri-Block DB3D (Techne, Staffordshire, UK), after which they were left to reach room temperature. Afterwards, 5 mL of 5% potassium chloride was added and samples were then centrifuged for 6 min at 1000 rpm in a Fisher Scientific (Saint-Laurent, Canada), accuspin 3R, centrifuge. The upper layer was removed and used for the fatty acid methyl ester analysis by GC.

Fatty acid methyl esters were analysed by GC (Shimadzu, GC-2014, Kyoto, Japan) using a Varian CP-SIL 88 fused silica capillary column (100m × 0.25 mmID × 0.2 µm film thickness). Purified helium was used as a carrier gas with a head pressure of 109.9 kPa and a column flow of 0.43 mL/min. A split ratio of 89.8 and an injector temperature of 250 °C were used for the injection of the samples. A flame ionization detector (FID) was used for the identification and quantification of fatty acid methyl ester peaks using a detector temperature of 250 °C. One µL of sample was injected at an initial temperature of 50 °C which was held for 1 min. The temperature was then increased at a rate of 2 °C/min to 188 °C and held for 10 min, then raised at a rate of 2 °C/min to the final temperature of 240 °C, which was held for 44 min, giving a total runtime of 150 min. Identification of the peaks was possible with the use of a 37 FAME standard (Supelco, FAME mix C4-C24, 100 mg) and also confirmed by GC-MS using a Shimadzu (GCMS-QP2010) and the same column operating under the same temperature and gas flow rate conditions. Individual peak areas were expressed as percentage of the total peak area.

2.6. Statistical Analyses

The effects and interactions between factors on measured parameters were assessed by analysis of variance (ANOVA) derived from linear mixed-effects (LME) models [53] by using the 'nlme' package in R [54]. The hierarchical nature of the design was reflected in the random error structures that were specified as farm/year. The normality of the residuals of all models was tested using quantile–quantile (QQ) plots. Real means and standard errors of means were generated by using the 'tapply' function in R.

3. Results

3.1. Olive Fruit and Oil Yield

There were significant differences in olive fruit and oil yield levels between locations (Table 2). Yields were more than 50% lower in orchards located in the foothills when compared to orchards in the Messara Plain (Table 2).

Table 2. Effect of, and interaction between, harvest year (2006, 2007, 2008), production system (organic versus conventional) and location of fields (plain versus foot hills) on yields.

		Fruit Yield	**Oil Yield**
Factor		**t Olives/ha**	**kg Oil/ha**
Year	2006	6.0 ± 1.0	1184 ± 190
	2007	4.8 ±0.9	983 ± 202
	2008	5.9 ± 1.0	1190 ± 181
Production system	Organic	5.9 ± 0.8	1182 ± 148
	Conventional	5.2 ± 0.8	1066 ± 160
Location	Plain	7.3 ± 0.6	1426 ± 135
	Hills	3.7 ± 0.7	803 ± 142
ANOVA results (*p*-values)			
Main effects			
Year (Y)		ns	ns
BProduction system (PS)		ns	ns
Location (L)		0.0016	0.0059
Interactions			
Y × PS		ns	ns
Y × L		0.0080	0.0101
PS × L		ns	ns
Y × PS × L		ns	ns

Values shown are main effect means ± SE; ns: not significant ($p > 0.1$).

However, there was no significant difference in fruit and oil yields between years and orchards managed to organic farming and conventional farming standards, although it should be pointed out that both fruit and oil yields were numerically ~10% higher on the organic farms included in the survey (Table 2).

There was also a very highly significant interaction between year and location for both fruit and oil yield (Table 2), with the difference in fruit yield between orchards in the plain and the foothill being significant in 2006 and 2008, but not in 2007 (individual data not shown).

There were significant main effects of year and production systems on the water and oil content of olive fruit and a main effect of location on the water content of olive fruit (Table 3). The water content was approx. 10% higher and oil content 9% lower in 2008, and organic olives had a higher oil content and lower water content than conventionally produced olives. There were also significant effects of year on the oil content when calculated on a dry weight basis and of location on the water content.

Table 3. Effect of, and interaction between, harvest year (2007, 2008), production system (organic versus conventional) and location of fields (plain versus foot hills) on olive fruit composition.

		Water Content	Oil Content	
Factor		**% of Fresh Weight**	**% of Fresh Weight**	**% of Dry Weight**
Year	2007	48.0 ± 1.5	25.3 ± 0.9	48.6 ± 0.7
	2008	53.8 ± 1.2	20.5 ± 0.7	44.4 ± 1.0
Production system	Organic	49.1 ± 1.4	23.9 ± 1.2	46.8 ± 1.3
	Conventional	52.8 ± 1.8	21.9 ± 1.1	46.2 ± 1.0
Location	Plain	49.2 ± 1.1	23.8 ± 0.9	46.7 ± 1.0
	Hills	52.7 ± 1.9	22.0 ± 1.4	46.4 ± 1.3
ANOVA results (p-values)				
Main effects				
Year (Y)		0.0018	0.0004	0.0213
Production system (PS)		0.0186	0.0336	ns
Location (L)		0.0226	T	ns
Interactions				
Y × PS		ns	ns	ns
Y × L		ns	ns	ns
PS × L		0.0290	0.0298	ns
Y × PS × L		ns	ns	ns

Values shown are main effect means ± SE; ns: not significant ($p > 0.1$); T, trend ($0.1 > p > 0.05$).

The water content was higher in olive fruit produced in the foothills when compared to those produced in the Messara Plain (Table 3).

There were also significant interactions between production system and location for water and oil content calculated on a fresh weight basis (Table 3). The water content was significantly higher and there was a trend ($0.1 > p > 0.05$) towards a significantly lower oil content in conventional olive fruit from fields in the foothills, while water and oil content were similar in organic and conventional fruit from fields in the Messara Plain and organic fruit from the foothills (individual data not shown).

3.2. Oil Acidity and Peroxide Value

For olive oil to be classified as "Extra Virgin", its free acidity, expressed as oleic acid, should be not more than 0.8 g per 100 g (0.8%), and it needs to have other specific characteristics (e.g., peroxide value) which correspond to the specifications for this category by the International Olive Oil Council (2003).

There were significant effects of year, production system and location on the free acidity of olive oil, with acidity being approx. 25% higher in 2008 compared to 2007, 9% higher in organic compared to conventional olive oil and 9% higher in oil produced from olives harvested in the foothills compared to oil from olives produced in the Messara Plain (Table 4).

Table 4. Effect of, and interaction between, harvest year (2007, 2008), production system (organic versus conventional) and location of fields (plain versus foot hills) on selected olive oil quality parameters (free acidity, peroxide value).

		Free Acidity	Peroxide Value
Factor		**%**	**Meq O_2 kg/Oil**
Year	2007	0.31 ± 0.02	5.32 ± 0.24
	2008	0.40 ± 0.01	3.06 ± 0.39
Production system	Organic	0.37 ± 0.02	4.27 ± 0.59
	Conventional	0.34 ± 0.02	4.11 ± 0.47
Location	Plain	0.34 ± 0.02	3.68 ± 0.49
	Hills	0.37 ± 0.02	4.71 ± 0.50
Extra virgin classification		<0.8	<20
ANOVA results (*p*-values)			
Main effects			
Year (Y)		<0.0001	0.0003
Production system (PS)		0.0056	ns
Location (L)		0.0391	0.0274
Interactions			
Y × PS		ns	ns
Y × L		0.0410	ns
PS × L		T	ns
Y × PS × L		ns	ns

Values shown are main effect means ± SE; ns: not significant ($p > 0.1$); T: trend ($0.1 > p > 0.05$).

There was also a significant interaction between year and geographic location. Free acidity was significantly higher in the foothills in 2007 while there was no significant difference between the plain and foothills in 2008.

There were significant effects of year and location on the peroxide value, which was higher in year 2007 compared to 2008 and higher in oil from the foothills compared to oil produced from olives harvested in the Messara Plain (Table 4).

In contrast, there were no significant effects of production system for the other oxidation-related quality parameters assessed (K_{270}, $K_{232,}$ K_{262}, K_{268}, K_{274} and ΔK) (Table 5).

However, there was a small, but significant, effect of year for K_{270} (with values being higher in 2008) and a small, but significant, effect of location for $K_{232,}$ (with values being higher in the foothills) (Table 5).

There was also a significant interaction between year and location for K_{232}. In 2007, there was no significant difference between the plain and foothills for $K_{232,}$ while in 2008 K_{232} values were higher in the foothills (individual data not shown).

The fatty acid composition of olive oil was assessed in olive crops harvested in 2007 and 2008. In 2007, when a relatively small number of samples (oil from four organically and four conventionally managed orchards) were included in the analyses, no significant differences in fatty acid composition could be detected between oil produced from organically and conventionally grown olives (individual data not shown).

In 2008, oil samples from a larger number of orchards (four organically and conventionally managed orchards in both the foothills and Messara Plain) were included in analysis and some small, but significant, main effects and interactions were detected for some fatty acids.

When data for saturated fatty acid (SFA) were compared, location had a significant main effect on palmitic acid, the main SFA found in olive oil, which was found in significantly (10%) higher levels in oil from orchards located in the foothills (Table 6). No significant effects of location and production system were detected for myristic acid (C14:0) and heptadecaonic acid (C17:0), although there was a significant significant interaction ($p = 0.0061$) for behenic acid (C22:0); although detected in olive oil, these three SFA accounted for less than 0.2% of the total fatty acids (individual results not shown).

Table 5. Effect of, and interaction between (a) year (2007 or 2008), (b) production system (organic or conventional) and (c) location (plain or foothills) on oxidation related parameters (K_{270}, K_{232}, K_{262}, K_{268}, K_{274} and ΔK) in olive oil.

Factor		K_{270}	K_{232}	K_{262}	K_{268}	K_{274}	ΔK
Year	2006/2007	0.171 ± 0.008	1.729 ± 0.040	0.203 ± 0.010	0.180 ± 0.009	0.163 ± 0.007	−0.0032 ± 0.0036
	2007/2008	0.206 ± 0.012	1.753 ± 0.071	0.226 ± 0.016	0.196 ± 0.014	0.186 ± 0.015	−0.0103 ± 0.0012
Production system	Organic	0.198 ± 0.013	1.795 ± 0.054	0.224 ± 0.014	0.198 ± 0.012	0.183 ± 0.013	−0.0062 ± 0.0034
	Conventional	0.179 ± 0.011	1.686 ± 0.054	0.204 ± 0.013	0.178 ± 0.011	0.165 ± 0.011	−0.0072 ± 0.0025
Location	Plain	0.178 ± 0.008	1.668 ± 0.041	0.207 ± 0.012	0.178 ± 0.009	0.161 ± 0.009	−0.0063 ± 0.0035
	Hills	0.199 ± 0.015	1.814 ± 0.059	0.221 ± 0.016	0.197 ± 0.013	0.188 ± 0.014	−0.0072 ± 0.0024
Extra virgin classification		<0.22	<2.5		<0.22		<0.01
ANOVA results (*p*-values)							
Main effects							
Year (Y)		0.0245	ns	ns	ns	ns	ns
Production system (PS)		ns	ns	ns	ns	ns	ns
Location (L)		ns	0.0418	ns	ns	T	ns
Interactions							
Y × PS		ns	ns	ns	ns	ns	ns
Y × L		T	0.0290	ns	ns	T	ns
PS × L		ns	ns	ns	ns	ns	ns
Y × PS × L		ns	ns	ns	ns	ns	ns

Values shown are main effect means ± SE; ns: not significant ($p > 0.1$); T: trend ($0.1 > p > 0.05$).

Table 6. Effect of, and interaction between, production system (organic versus conventional) and geographic location (Messara Plain or foothills) on the concentrations (% of total fatty acids) of the major fatty acids found in olive oil in harvest year 2008. Values shown are main effect means ± SE.

Fatty Acids	Production System (S)		Location (L)		ANOVA Results (*p*-Value) Main Effects		Interaction
	Organic	Conventional	Plain	Foothills	S	L	S × L
SFA							
Palmitic (C16:0)	12.1 ± 0.3	12.2 ± 0.3	11.5 ± 0.1	12.7 ± 0.3	ns	0.0026	ns
Stearic (C18:0)	2.5 ± 0.1	2.5 ± 0.1	2.5 ± 0.1	2.6 ± 0.1	ns	ns	ns
Arachidic (C20:0)	0.44 ± 0.01	0.44 ± 0.01	0.43 ± 0.01	0.45 ± 0.01	ns	ns	ns
MUFA							ns
Palmitoleic (C16:1c9)	0.78 ± 0.05	0.81 ± 0.05	0.71 ± 0.02	0.88 ± 0.04	ns	0.0056	ns
Oleic (C18:1c9)	76.5 ± 0.9	76.5 ± 0.5	77.4 ± 0.4	75.6 ± 0.7	ns	T	ns
Eicosenoic (C20:1c11)	0.28 ± 0.01	0.28 ± 0.01	0.28 ± 0.01	0.27 ± 0.01	ns	0.0255	ns
PUFA							
Linoleic (C18:2c9c12)	6.3 ± 0.4	6.1 ± 0.3	6.0 ± 0.3	6.4 ± 0.4	ns	ns	T
a-linolenic C18:3c5c9c12)	0.71 ± 0.03	0.74 ± 0.02	0.72 ± 0.03	0.728 ± 0.03	ns	ns	ns

Values shown are main effect means ± SE; ns: not significant ($p > 0.1$); T: trend ($0.1 > p > 0.05$).

When data for monounsaturated fatty acid (MUFA) were compared, no significant main effect of production system was detected for oleic acid, the main MUFA found in olive oil. However, there was a trend towards higher levels of oleic acid in oil from olives produced in the Messara Plain. Location had a significant main effect on some of the minor MUFA found in olive oil (palmitoleic acid and eicosenoic acid), with palmitoleic acid being higher in oil from orchards in the foothills and eicosenoic acid being higher in oil from the Messara Plain (Table 6). No significant effects of location and production systems were detected for heptadecanoic (C17:1 c10) which was found in very small concentrations (<0.07%) in olive oil samples (individual results not shown).

Similar to 2007, ANOVA detected no significant main and interaction effect of location and production system on the polyunsaturated fatty acid (PUFA) levels and composition (Table 6). However, there was a trend toward a significant interaction for linoleic acid (Table 6) and eicosadienoic acid, one of the minor PUFAs found in olive oil (individual results not shown).

4. Discussion

4.1. Crop Yield

As expected, yield levels in the orchards in the foothills (which have less fertile soil, and where irrigation water availability is more restricted) were substantially lower. Orchards in the foothills are known to have greater problems with soil erosion and lower organic matter content than orchards in the Messara Plain (which has less erosion problems, more fertile soils with higher organic matter levels, and access to irrigation water at all times) (interviews with farmers participated in the survey and other stakeholders such as olive millers in the area).

In contrast, the finding of similar olive yields in organic compared to conventional production was unexpected, and contradicts results from several other studies elsewhere [28,35], although studies in Greece also reported similar yields for organic and conventional orchards [44,45]. This could have been due to a range of factors.

One reason could be that organic olive production in the Messara region (where this survey was carried out) started much earlier than in many other regions in Greece and the Mediterranean (more than 30 years ago) and has developed into a very mature and well-organised industry [36,44,55]. Organic farmers in the region are known to have developed locally adapted agronomic protocols, e.g., appropriate timings and methods for canopy management [55,56] and systems of fertilisation (e.g., systems for exchanging manure for forage crops grown in olive orchards during the winter months and growing vetch and other fertility building crops in olive orchards over the rainfall period) [36]. This could explain the lack of fertility and nutrient-management-related yield reductions in organic production in the Messara Valley.

Another factor could be that olive fly pest pressure is relatively low in the Messara region, and in the 3 years in which yields were monitored, pest pressure was very low. Olive fly damage has previously been described as a major reason/factor for yield reductions in olive production [33,57]. The results reported here suggest that the use of mass trapping systems for the control of the olive fly in combination with the environment conditions in the Messara region (high temperature and low relative humidity during summer months) was sufficient to control olive fly and prevent adverse effects on yields and quality parameters of olive oil.

Since the oil content was higher in olives from organic orchards, the oil yield per unit area was slightly higher in organic production, suggesting that the more widespread use of organic production methods may increase rather than decrease olive oil yields in Southern Crete and other regions in the Mediterranean with similar semi-arid climatic conditions and with hot, dry summers. In this context, it is important to note that a recent study comparing yields in organic and conventional spelt wheat production in the Messara region reported significantly higher yields in organic compared to conventional production systems [58]. The study describes that improvement in soil water retention and water use efficiency associated with regular organic matter inputs in organic production systems may partially explain the higher crop yields with organic management under semi-arid conditions [58].

4.2. Oil Acidity and Peroxide Value

Oil acidity and peroxide value (which are major quality parameters) were in the lower range expected for "extra virgin" olive oil in accordance with the International Olive Oil Council (IOOC) standards [59], which indicates a high quality, extra virgin olive oil. Oil acidity and peroxide value were affected by year and geographic location, thus confirming previous studies which indicated that climatic conditions and geographic factors (e.g., elevation and soil type) significantly affect acidity and other quality parameters of olive oil [29,35]. The finding that oil yield can be increased via more intensive management practices in the Messara Plain, without a significant reduction in olive oil quality, indicates that the levels of intensity of production used in the region do not affect quality.

However, the finding of slightly, but significantly, higher levels of acidity in organic olive oil indicates that organic production methods could be further improved, especially with regard to the management of the olive fly, since olive fly infestation is known to increase acidity even at infestation levels where yield is not affected [33]. This may not be of great importance in the Messara region, where acidity levels are usually very low in both production systems. However, in areas with higher olive fly pest pressure, there may be a greater negative effect of using organic production methods on olive oil quality, unless more effective protocols for controlling olive fly infestation that are acceptable under organic farming standards are developed and used [37].

4.3. Fatty Acid Profiles

The fatty acid composition of the olive oils from all production systems and elevations included in the study conformed to the IOOC standards for high-quality extra virgin olive oil [48]. The finding of lower levels of the nutritionally undesirable palmitic acid and a trend towards higher levels of nutritionally desirable oleic acid in olive oil from orchards located in the plain indicates that the better soil fertility and/or "higher input" production methods used in the Messara Plain may have a small beneficial effect on the nutritional composition of olive oil.

There are a very limited number of studies into the fatty acid composition of olive oil from organic production. However, the few studies available reported similar results to those presented here, with both Gutiérrez et al. [27] and Samman et al. [29] reporting no major differences in fatty acid composition between organic and conventional olive oils.

It is important to note that concentrations of nutritionally desirable phenolic compounds were not assessed in this study and that a study in Spain reported higher levels of phenolic compounds in organic compared to conventional olive oil [25], while a study in Turkey did not find significant differences [32]. These results are consistent with the findings of recent systematic reviews and meta-analyses which reported that organic production methods result in higher (poly)phenolics/antioxidant levels in a wide range of crop species [6,21,23]. Future studies should therefore focus on gaining a more detailed understanding of how contrasting olive management practices used in organic and conventional production affect the concentrations of nutritionally desirable (poly)phenolics and other phytochemicals with antioxidant activity.

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References

1. Madžarić, S.; Al Bitar, L.; Bteich, M.R.; Pugliese, P. Mediterranean Organic Agriculture Network—Report 2019. Available online: https://moan.iamb.it/wp-content/uploads/2021/10/Mediterranean-Organic-Agriculture-Network-Report-2019.pdf (accessed on 28 April 2022).
2. Porter, W.P.; Green, S.M.; Debbink, N.L.; Carlson, I. Groundwater pesticides—Interactive effects of low concentrations of carbamates aldicarb and methomyl and the triazine metribuzin on thyroxine and somatrophin levels in white rats. *J. Toxicol. Environ. Health Part A* **1993**, *40*, 15–34. [CrossRef] [PubMed]
3. Drinkwater, L.E.; Wagoner, P.; Sarrantonio, M. Legume-based cropping systems have reduced carbon and nitrogen losses. *Nature* **1998**, *396*, 262–264. [CrossRef]
4. Tuomisto, H.L.; Hodge, I.D.; Riordan, P.; Macdonald, D.W. Does organic farming reduce environmental impacts?—A meta-analysis of European research. *J. Environ. Manag.* **2012**, *112*, 309–320. [CrossRef] [PubMed]
5. Gomiero, T.; Pimentel, D.; Paoletti, M.G. Environmental Impact of Different Agricultural Management Practices: Conventional vs. Organic Agriculture. *Crit. Rev. Plant Sci.* **2011**, *30*, 95–124. [CrossRef]
6. Rempelos, L.; Baranski, M.; Wang, J.; Adams, T.N.; Adebusuyi, K.; Beckman, J.J.; Brockbank, C.J.; Douglas, B.S.; Feng, T.; Greenway, J.D.; et al. Integrated Soil and Crop Management in Organic Agriculture: A Logical Framework to Ensure Food Quality and Human Health? *Agronomy* **2021**, *11*, 2494. [CrossRef]
7. Stoate, C.; Boatman, N.D.; Borralho, R.J.; Carvalho, C.R.; de Snoo, G.R.; Eden, P. Ecological impacts of arable intensification in Europe. *J. Environ. Manag.* **2001**, *63*, 337–365. [CrossRef]
8. Bengtsson, J.; Ahnstrom, J.; Weibull, A.C. The effects of organic agriculture on biodiversity and abundance: A meta-analysis. *J. Appl. Ecol.* **2005**, *42*, 261–269. [CrossRef]
9. Pysek, P.; Jarosik, V.; Kropac, Z.; Chytry, M.; Wild, J.; Tichy, L. Effects of abiotic factors on species richness and cover in Central European weed communities. *Agric. Ecosyst. Environ.* **2005**, *109*, 1–8. [CrossRef]
10. Hole, D.G.; Perkins, A.J.; Wilson, J.D.; Alexander, I.H.; Grice, P.V.; Evans, A.D. Does organic farming benefit biodiversity? *Biol. Conserv.* **2005**, *122*, 113–130. [CrossRef]
11. Tuck, S.L.; Winqvist, C.; Mota, F.; Ahnstrom, J.; Turnbull, L.A.; Bengtsson, J. Land-use intensity and the effects of organic farming on biodiversity: A hierarchical meta-analysis. *J. Appl. Ecol.* **2014**, *51*, 746–755. [CrossRef]
12. Dubois, D.; Gunst, L.; Fried, P.M.; Stauffer, W.; Spiess, E.; Alfoldi, T.; Fliessbach, A.; Frei, R.; Niggli, U. DOC-trial: Yields and energy use efficiency. *Agrarforschung* **1999**, *6*, 293–296.
13. Cormack, W.F. Energy Use in Organic Farming Systems—Final Report of Defra Project OF0182. 2000. Available online: https://orgprints.org/id/eprint/8169/ (accessed on 28 April 2022).
14. Bos, J.F.F.P.; de Haan, J.; Sukkel, W.; Schils, R.L.M. Energy use and greenhouse gas emissions in organic and conventional farming systems in the Netherlands. *NJAS—Wagen. J. Life Sci.* **2014**, *68*, 61–70. [CrossRef]
15. Pretty, J.N.; Ball, A.S.; Li, X.Y.; Ravindranath, N.H. The role of sustainable agriculture and renewable-resource management in reducing greenhouse-gas emissions and increasing sinks in China and India. *Philos. Trans. R. Soc. A* **2002**, *360*, 1741–1761. [CrossRef] [PubMed]
16. Squalli, J.; Adamkiewicz, G. Organic farming and greenhouse gas emissions: A longitudinal U.S. state-level study. *J. Clean. Prod.* **2018**, *192*, 30–42. [CrossRef]
17. Skinner, C.; Gattinger, A.; Krauss, M.; Krause, H.-M.; Mayer, J.; van der Heijden, M.G.A.; Mäder, P. The impact of long-term organic farming on soil-derived greenhouse gas emissions. *Sci. Rep.* **2019**, *9*, 1702. [CrossRef] [PubMed]
18. Maffia, A.; Pergola, M.; Palese, A.M.; Celano, G. Environmental Impact Assessment of Organic vs. Integrated Olive-Oil Systems in Mediterranean Context. *Agronomy* **2020**, *10*, 416. [CrossRef]
19. Stolz, H.; Stolze, M.; Hamm, U.; Janssen, M.; Ruto, E. Consumer attitudes towards organic versus conventional food with specific quality attributes. *NJAS—Wagen. J. Life Sci.* **2011**, *58*, 67–72. [CrossRef]
20. Joshi, Y.; Rahman, Z. Factors Affecting Green Purchase Behaviour and Future Research Directions. *Int. Strateg. Manag. Rev.* **2015**, *3*, 128–143. [CrossRef]
21. Baranski, M.; Srednicka-Tober, D.; Volakakis, N.; Seal, C.; Sanderson, R.; Stewart, G.B.; Benbrook, C.; Biavati, B.; Markellou, E.; Giotis, H.; et al. Higher antioxidant and lower cadmium concentrations and lower incidence of pesticide residues in organically grown crops: A systematic literature review and meta-analysis. *Br. J. Nutr.* **2014**, *112*, 794–811. [CrossRef]
22. Mie, A.; Andersen, H.R.; Gunnarsson, S.; Kahl, J.; Kesse-Guyot, E.; Rembiałkowska, E.; Quaglio, G.; Grandjean, P. Human health implications of organic food and organic agriculture: A comprehensive review. *Environ. Health* **2017**, *16*, 111. [CrossRef]
23. Rempelos, L.; Wang, J.; Baranski, M.; Watson, A.; Volakakis, N.; Hoppe, H.-W.; Kühn-Velten, W.N.; Hadall, C.; Hasanaliyeva, G.; Chatzidimitriou, E.; et al. Diet and food type affect urinary pesticide residue excretion profiles in healthy individuals: Results of a randomized controlled dietary intervention trial. *Am. J. Clin. Nutr.* **2021**, *115*, 364–377. [CrossRef] [PubMed]
24. Leifert, C. Organic Farming Provides a Blueprint to Improve Food Quality, Safety and Security. *Agronomy* **2022**, *12*, 631. [CrossRef]
25. López-Yerena, A.; Lozano-Castellón, J.; Olmo-Cunillera, A.; Tresserra-Rimbau, A.; Quifer-Rada, P.; Jiménez, B.; Pérez, M.; Vallverdú-Queralt, A. Effects of Organic and Conventional Growing Systems on the Phenolic Profile of Extra-Virgin Olive Oil. *Molecules* **2019**, *24*, 1986. [CrossRef] [PubMed]
26. Berg, H.; Maneas, G.; Salguero Engström, A. A Comparison between Organic and Conventional Olive Farming in Messenia, Greece. *Horticulturae* **2018**, *4*, 15. [CrossRef]

27. Gutierrez, F.; Arnaud, T.; Parra Lopez Albi, M.A. Influence of ecological cultivation on virgin olive oil quality. *J. Am. Oil Chem. Soc.* **1999**, *76*, 617–621. [CrossRef]
28. Parra Lopez, C.; Calatrava Requena, J. Factors related to the adoption of organic farming in Spanish olive orchards. Span. *J. Agric. Res.* **2005**, *3*, 5–16.
29. Samman, S.; Chow, J.W.Y.; Foster, M.J.; Ahmad, Z.I.; Phuyal, J.L.; Petocz, P. Fatty acid composition of edible oils derived from certified organic and conventional agricultural methods. *Food Chem.* **2008**, *109*, 670–674. [CrossRef]
30. Lentza-Rizos, C.; Avramides, E.J. Pesticide residues in olive oil. *Rev. Environ. Contam. Toxicol.* **1995**, *141*, 111–134.
31. Tsatsakis, A.M.; Tsakiris, I.N.; Tzatzarakis, M.N.; Agourakis, Z.B.; Tutudaki, M.; Alegakis, A.K. Three-year study of fenthion and dimethoate pesticides in olive oil from organic and conventional cultivation. *Food Addit. Contam.* **2003**, *20*, 553–559. [CrossRef]
32. Dolgun, O.; Ozkan, G.; Erbay, B. Comparison of Olive Oils Derived from Certified Organic and Conventional Agricultural Methods. *Asian J. Chem.* **2010**, *22*, 2339–2348. Available online: https://asianjournalofchemistry.co.in/User/ViewFreeArticle.aspx?ArticleID=22_3_92 (accessed on 6 June 2022).
33. Neuenschwander, P.; Michelakis, S. Infestation of Dacus oleae (Gmel.) (Diptera, Tephritidae) at harvest time and its influence on yield and quality of olive oil in Crete. *Z. Angew. Entomol.* **1978**, *86*, 420–433. [CrossRef]
34. Volakakis, N. Development of Strategies to Improve the Quality and Productivity of Organic and 'Low Input' Olive Production Systems in Semi-Arid Mediterranean Regions. Ph.D. Thesis, Newcastle University, Newcastle Upon Tyne, UK, 2010.
35. Tzouvelekas, V.; Pantzios, C.J.; Fotopoulos, C. Technical efficiency of alternative farming systems: The case of Greek organic and conventional olive-growing farms. *Food Policy* **2001**, *26*, 549–569. [CrossRef]
36. Kabourakis, E. Code of practices for ecological olive production systems. *Olivae* **1999**, *77*, 46–55.
37. Daher, E.; Cinosi, N.; Chierici, E.; Rondoni, G.; Famiani, F.; Conti, E. Field and Laboratory Efficacy of Low-Impact Commercial Products in Preventing Olive Fruit Fly, Bactrocera oleae, Infestation. *Insects* **2022**, *13*, 213. [CrossRef] [PubMed]
38. Broumas, T.; Haniotakis, G.; Liaropoulos, C.; Tomazou, T.; Ragoussis, N. The efficacy of an improved form of the mass-trapping method, for the control of the olive fruit fly, Bactrocera oleae (Gmelin) (Dipt., Tephritidae): Pilot-scale feasibility studies. *J. Appl. Entomol.* **2002**, *126*, 217–223. [CrossRef]
39. Noce, M.E.; Belfiore, T.; Scalercio, S.; Vizzarri, V.; Iannotta, N. Efficacy of new mass-trapping devices against Bactrocera oleae (Diptera tephritidae) for minimizing pesticide input in agroecosystems. *J. Environ. Sci. Health B* **2009**, *44*, 442–448. [CrossRef]
40. Seufert, V.; Ramankutty, N.; Foley, J.A. Comparing the yields in organic and conventional agriculture. *Nature* **2012**, *485*, 229–234. [CrossRef]
41. De Ponti, T.; Rijk, B.; van Ittersum, M.K. The crop yield gap between organic and conventional agriculture. *Agric. Syst.* **2012**, *108*, 1–9. [CrossRef]
42. Wilbois, K.-P.; Schmidt, J.E. Reframing the Debate Surrounding the Yield Gap between Organic and Conventional Farming. *Agronomy* **2019**, *9*, 82. [CrossRef]
43. Schram, M.; de Haan, J.J.; Kroonen, M.; Verstegen, H.; Van der Putten, W.H. Crop yield gap and stability in organic and conventional farming systems. *Agric. Ecosyst. Environ.* **2018**, *256*, 123–130. [CrossRef]
44. Vassiliou, A. Farm Structure Optimisation of, and the Impact of Widespread Conversion to Ecological Olive Production Systems. Ph.D. Thesis, Institute of Rural Studies, University of Wales, Aberystwyth, UK, 2000.
45. Gkisakis, V.D.; Volakakis, N.G.; Kosmas, E.; Kabourakis, E.M. Developing a decision support tool for evaluating the environmental performance of olive production in terms of energy use and greenhouse gas emissions. *Sustain. Prod. Consum.* **2020**, *24*, 156–168. [CrossRef]
46. EU. Council Regulation (EC) No 834/2007 of 28 June 2007 on Organic Production and Labelling of Organic Products and Repealing Regulation (EEC) No 2092/91. *Off. J. Eur. Communities* **2007**, *L 189*, 1–22. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32007R0834&from=EN (accessed on 28 April 2022).
47. Association of Analytical Chemists. *Standard Official Methods of Analysis of the Association of Analytical Chemists*, 14th ed.; Williams, S.W., Ed.; AOAC: Washington, DC, USA, 1984.
48. EU Commission Regulation. Commission Regulation (EEC) No 2568/91 of 11 July 1991 on the characteristics of olive oil and olive-residue oil and on the relevant methods of analysis. *Off. J. Eur. Communities* **1991**, *L 248*, 1–83. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:31991R2568&from=EN (accessed on 28 April 2022).
49. Kiritsakis, A. *Olive Oil*; American Oil Chemists' Society: Champaign, IL, USA, 1991; pp. 137–139.
50. Kiritsakis, A.; Dugan, L.R. Studies in photooxidation of olive oil. *J. Am. Oil Chem. Soc.* **1985**, *62*, 892–896. [CrossRef]
51. Kiritsakis, A.; Keceli, M.T.; Kiritsakis, K. Olive Oil. In *Bailey's Industrial Oil and Fat Products*; Shahidi, F., Ed.; John Wiley & Sons: Toronto, ON, Canada, 2020; pp. 307–344.
52. Shahidi, F.; Ambigaipalan, P.; Kiritsakis, A. Analysis of Olive Oil Quality. In *Olives and Olive Oil as Functional Foods*; Kiritsakis, A., Shahidi, F., Eds.; John Wiley and Sons: Toronto, ON, Canada, 2017; pp. 521–531.
53. Pinheiro, J.; Bates, D. *Mixed-Effects Models in S and S-PLUS*; Springer Science & Business Media: New York, NY, USA, 2006.
54. R Core Team. *R: A Language and Environment for Statistical Computing*; R Core Team: Vienna, Austria, 2018; Available online: www.gbif.org/tool/81287/r-a-language-and-environment-for-statistical-computing (accessed on 28 April 2022).
55. Kabourakis, E. Prototyping and Dissemination of Ecological Olive Production Systems. A Methodology for Designing and Dissemination of Prototype Ecological Olive Production Systems (EOPS) in Crete. Ph.D. Thesis, Landbouw Universiteit, Wageningen, The Netherlands, 1996.

56. Kabourakis, E. Learning processes in designing and disseminating ecological olive production systems in Crete. In *Cow Up a Tree: Knowing and Learning for Change in Agriculture*; Cerf, M., Gibbon, D., Hubert, B., Jiggins, J., Paine, M., Proost, J., Rolling, N., Eds.; Case Studies from Industrialised Countries; INRA Editions: Paris, France, 2000; pp. 97–111.
57. Economopoulos, A.P.; Haniotakis, G.E.; Michelakis, S. Population studies on the olive fruit fly, Dacus oleae (Gmel.) (Dipt., Tephritidae) in Western Crete. *J. Appl. Entomol.* **1982**, *93*, 463–476. [CrossRef]
58. Wang, J.; Baranski, M.; Korkut, R.; Kalee, H.A.; Wood, L.; Bilsborrow, P.; Janovska, D.; Leifert, A.; Winter, S.; Willson, A.; et al. Performance of Modern and Traditional Spelt Wheat (Triticum spelta) Varieties in Rain-Fed and Irrigated, Organic and Conventional Production Systems in a Semi-Arid Environment; Results from Exploratory Field Experiments in Crete, Greece. *Agronomy* **2021**, *11*, 890. [CrossRef]
59. International Olive Oil Council (IOOC). Trade Standard Applying to Olive Oil and Olive-Pomace Oil, Revised. COI/T.15/NC No 3/Rev. 15. International Olive Council, Madrid, ES. 2019. Available online: www.internationaloliveoil.org/wp-content/uploads/2020/07/Trade-standard-T15-NC3-Rev15-EN.pdf (accessed on 28 April 2022).