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# Horticultural performance of 23 Sicilian olive genotypes in hedgerow systems: Vegetative growth, productive potential and oil quality

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ABSTRACT

The super high density (SHD) model is a new olive growing system characterized by earlier and higher yields, fully mechanized harvesting and reduced orchard management costs. Until recently all commercial SHD orchards were planted primarily with three varieties: 'Arbequina', 'Arbosana' and 'Koroneiki'. To increase variety diversity, broaden available olive oil chemical and organoleptic profiles, and olive oils for marketing, minor local varieties should be evaluated for adaptability to the SHD system. This study compares multiple Sicilian native genotypes to the three current cultivars 'Arbequina', 'Arbosana' and 'Koroneiki'. The cumulative fruit and oil production, trunk-cross section area, canopy volume, alternate bearing behavior and oil quality were evaluated in a SHD system. Among the standard cultivars 'Koroneiki' had significantly higher and 'Arbequina' average productivity respectively compared to earlier reports and was chosen as the reference for evaluating the performance of the Sicilian genotypes. Many of the genotypes investigated had olive and oil yields equal to or higher than 'Arbequina'; 'Abunara' and 'ADE' had very high productivity. 'Abunara' produced a medium-high quality oil. The 'KALAT' selection had high productivity and low vigor, and therefore high productive efficiency. However, the oil polyphenols were low. The 'Cerasuola' and 'Piricuddara' cultivars had good productivity and a very high quality oils. These results confirm the need to evaluate and preserve local genetic resources as a strategy for improving SHD olive management and increasing olive cultivar and oil diversity.



## 1. Introduction

In the last two decades, the olive oil industry has experienced major production changes. The newer olive producing countries, as well as many traditional olive growing countries, are adopting the super high density (SHD) system, that facilitates mechanized harvesting and pruning. The SHD plantings sharply reduce management and production costs compared to the lower yielding hand-harvested traditional orchards (Deidda et al., 2006; Godini, 2009).

Currently SHD production utilizes three specific cultivars characterized by early bearing, high and constant productivity, and low vegetative vigor: the Spanish 'Arbequina' and 'Arbosana' and the Greek 'Koroneiki' (Avidan et al., 2011; Baldoni and Belaj, 2009; Bellini et al., 2008; Rallo et al., 2008; Tous et al., 2003). The consequence of widespread adoption of the SHD system is the loss of the local cultivars that produce high quality oils using traditional methods. The final result will be a loss of olive germplasm and oil diversity. To prevent this loss of cultivar and oil diversity, local cultivars should be evaluated for their adaptability to SHD production.

Among the evaluations thus far Farinelli and Tombesi (2015) compared the growth and productivity of four Italian varieties relative to the 'Arbequina' cultivar. They reported Italian cultivar 'Maurino' suitable for SHD orchards. In Apulia, various trials, comparing Italian varieties for suitability to the SHD system (Bellomo and Godini, 2003; Camposeo et al., 2008; Camposeo and Giorgio, 2006; Godini et al., 2006a, 2006b), found only 'Urano®' suitable for SHD production. All other varieties were unsuitable due to excessive vigor, spreading habit, late bearing and/or susceptibility to fruit bruising (Camposeo and Godini, 2010).

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**Table 1**
List of the 6 major Sicilian cultivars, the 15 minor Sicilian cultivars, the 2 selections and of the 3 international cultivars planted in 2006 in a high-density system (1140 t/ha).

| Main cultivars | Minor cultivars | Selections | International cultivars |
|---|---|---|---|
| Biancolilla | Abunara | ADE | Arbequina |
| Cerasuola | Bottone di gallo | KALAT | Arbosana |
| Moresca | Brandofino | | Koroneiki |
| Nocellara del Belice | Castriciana | | |
| Tonda iblea | Cavalieri | | |
| Oglialora Messinese | Crastu | | |
| | Erbano | | |
| | Giarraffa | | |
| | Minuta | | |
| | Nasitana | | |
| | Nerba | | |
| | Nocellara Messinese | | |
| | Olivo di Mandanici | | |
| | Piricuddara | | |
| | Vaddarica | | |

In the traditional olive growing countries, many “minor” cultivars are produced, some represented by as little as a single wild ancient tree (Rallo, 2005; Zohary and Spiegel-Roy, 1975; Sedgley and Wirthensohn, 2000). Fortunately, many have been collected, conserved and characterized (Alba et al., 2009; Bracci et al., 2009; Caruso et al., 2007, 2014b; Corrado et al., 2009; Erre et al., 2010; La Mantia et al., 2005; Marchese et al., 2016a,b; Marra et al., 2013; Muzzalupo et al., 2007; Rao et al., 2009; Rotondi et al., 2003; Sensi et al., 2003). However, this large genetic collection of native genotypes has not been evaluated for SHD production. The objective of this trial was to evaluate the suitability of 21 Sicilian cultivars and two new selections for SHD production. The horticultural, vegetative and productive performance of these 23 genotypes was compared to those of three standard SHD cultivars ‘Arbequina’, ‘Arbosana’ and ‘Koroneiki’, grown within the same environment. The final objective was to identify genotypes that are suitable for high density systems while providing high quality oils which also diversify the oil chemical profiles.

## 2. Materials and methods

### 2.1. Experimental site

The experimental orchard was planted with one-year-old self-rooted 50–70 cm plants in February 2006 in a traditional olive-growing area in southern Italy (Sicily) (37°31′ N, 13°03′ E and at 56 m asl). The typically Mediterranean climate is characterized by hot dry summers and mild winters with an annual average rainfall of 500–600 mm. The soil was a typical Red Mediterranean soil with 69% sand, 13% silt and 18% clay, 7.9 pH and 1.1% dry matter. The three “international” cultivars, ‘Arbequina’, ‘Arbosana’ and ‘Koroneiki’, were the SHD controls for six major Sicilian cultivars, 15 minor or neglected Sicilian cultivars (Caruso et al., 2007) and two genotypes selected by the Department of Agricultural and Forest Sciences of the University of Palermo (Table 1). Growth and production were monitored from 2009 to 2015.

### 2.2. Experimental design and orchard management

The 25 plants per cultivar/genotype, spaced 2.5 × 3.5 m (about 1140 trees/ha), were planted in a single north-south row. The trees were pruned lightly during the first 5 years after planting (YAP) to facilitate evaluation of vigor and early bearing. Only trunk branches below 60 cm from the soil were pruned. During the 2011 dormant season the trees were mechanically topped and hedged and trained to a free palmate shape to facilitate mechanical harvesting with an over the row straddle harvester. Weekly irrigation from July through mid-September was delivered by five self-compensating in-line drippers per plant spaced at 50 cm intervals which delivered 1.6 l/h. The total seasonal application rate was 800 $m^3$/ha/year.

### 2.3. Measurements

From the 3th to the 7h YAP yield per tree was measured on 8 randomly selected trees per genotype.

The Alternate Bearing Index, ABI, which quantifies the degree of annual yield variation was then calculated for the 4th to the 7th for each cultivar/genotype (Hoblyn et al., 1936):

$$\mathrm{ABI} = \frac{\sum_{t=2}^{n}\left(\frac{|y_t - y_{t-1}|}{y_t + y_{t-1}}\right)}{n-1}$$

where $y$ equals yield in a corresponding year $t$, and $n$ the total number of years. The unit free ABI, ranges from 0 and 1, with ABI = 0 designating no alternate bearing behavior and ABI = 1 total alternate bearing (Wood, 1989).

At the end of each growing season, trunk cross-section area (TCSA, $cm^2$) was measured at 50 cm above the ground level. The average TCSA and yield per ha ($t$) were used to calculate crop efficiency; CE = kg of fruit/$cm^2$ of TCSA. In the 2010 season, before the mechanical pruning was started, 12 plants per genotype were monitored for growth. Canopy height ($H$), width ($L_1$) and depth ($L_2$) were used to calculate total canopy volume (canopy volume = $L_1 \times L_2 \times H$). Immediately postharvest the olives fruits were washed, crushed by a hammer mill, the paste mixed at 20–25 °C for 20 min and the oil extracted by a continuous three-phase centrifuge system (Pieralisi M.A.I.P. S.p.A. model M3, Jesi, Italy). The resulting oil percentage and yield per ha were used to calculate oil yield per ha. Oil samples were stored in the dark at 11 °C until analysis using the European Communities official methods (Reg. EEC no. 2568/91).

### 2.4. Virgin olive oil analysis

Oil samples were analyzed for free acidity, peroxide value, polyphenol content, and fatty acid composition.

Total polyphenols were analyzed using the Folin–Ciocalteau colorimetric method (Arcoleo et al., 2006; Di Stefano and Guidoni, 1989; Picerno et al., 2003). The quantities were expressed as gallic acid ppm (Slinkard and Singleton, 1977). The fatty acid composition was determined by gas chromatographic analysis of the relative methyl esters, following the Mineo et al. (2007) protocol.

### 2.5. Statistical analysis

Statistical analysis of the data (ANOVA) was done using Systat (SYSTAT Software Inc., Chicago, IL). The Least Significant Differences (LSD) at $P \leq 0.05$ were calculated to separate means.

## 3. Results

### 3.1. Productivity

Three years after planting (2009), ‘Olivo di Mandanici’ was the most productive cultivar producing 5.6 t/ha followed by the three standard cultivars (‘Arbosana’, ‘Koroneiki’ and ‘Arbequina’) which collectively averaged 3.1 t/ha (Fig. 1a). The Sicilian cultivar ‘Minuta’ produced 2 t/ha while lower values were recorded in all the remaining cultivars. In 2010, production increased in all the cultivars (Fig. 1b). The control ‘Koroneiki’ produced 31 t/ha, significantly higher than all the other cultivars followed by ‘Bottone di Gallo’, ‘ADE’, ‘Abunara’, ‘Olivo di Mandanici’ and ‘Arbequina’ all with similar production of 14–15 t/ha. Slightly lower yields per ha

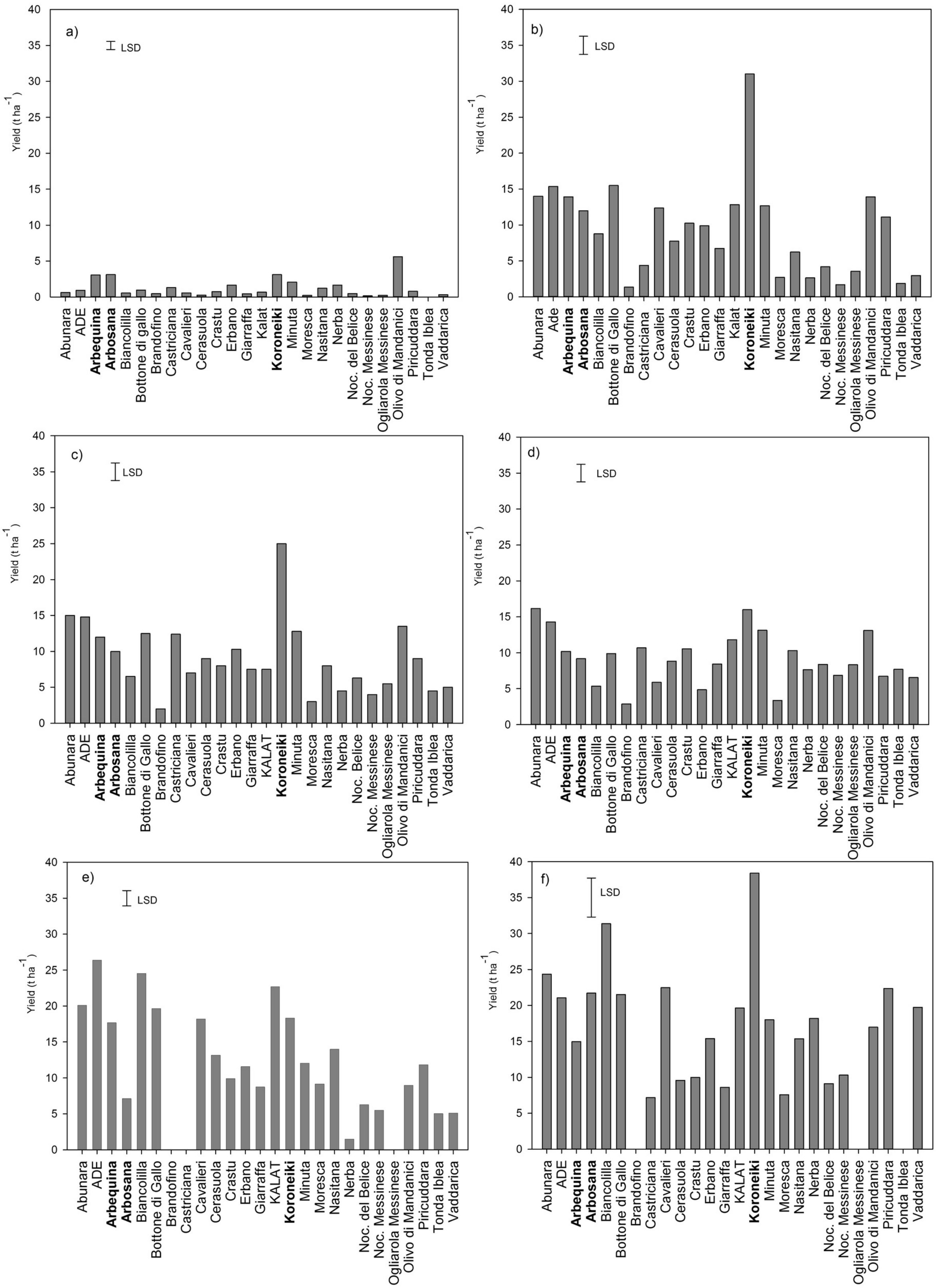


**Fig. 1.** Fruit yield (t/ha) in 2009 (a), 2010 (b), 2011 (c), 2012 (d), 2013 (e) and 2015 (f) of the 23 Sicilian genotypes planted in a high-density system (1140 trees/ha) as compared to the international varieties 'Arbequina', 'Arbosana' and 'Koroneiki'. LSD = least significant difference; d.f. = 182; $P < 0.001$.

(12 t/ha) were recorded for 'KALAT', 'Minuta', 'Cavalieri', 'Arbosana' and 'Piricuddara'. In 2011 (Fig. 1c), the 'Koroneiki' control was again the most productive cultivar, followed by 'Abunara' and 'ADE' at 15 t/ha and 'Olivo di Mandanici', 'Minuta', 'Bottone di Gallo', 'Castriciana' and 'Arbequina' which ranged from 23.5 to 12 t/ha. In 2012 (Fig. 1d), 'Abunara', 'Koroneiki' and 'ADE' had the highest yields producing 14–16 t/ha followed by 'Minuta', 'Olivo di Mandanici' and 'KALAT' which produced 12–13 t/ha. The other eight

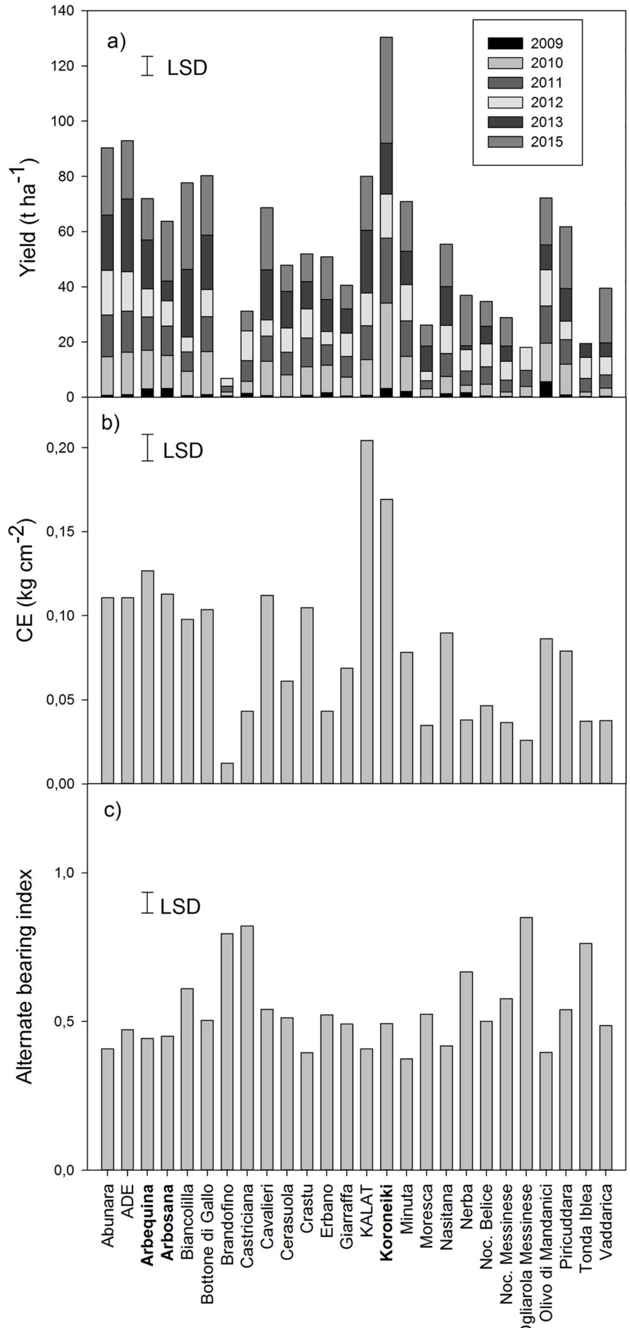


**Fig. 2.** Cumulative yield per ha (t/ha, a), average crop efficiency (CE, kg/cm$^2$, b) and alternate bearing index (AI, a) from the third (2009) to the ninth (2015) year after planting the 23 Sicilian genotypes in a high-density system (1140 trees/ha) as compared to the international varieties 'Arbequina', 'Arbosana' and 'Koroneiki'. LSD = least significant difference; d.f. = 182; $P < 0.001$.

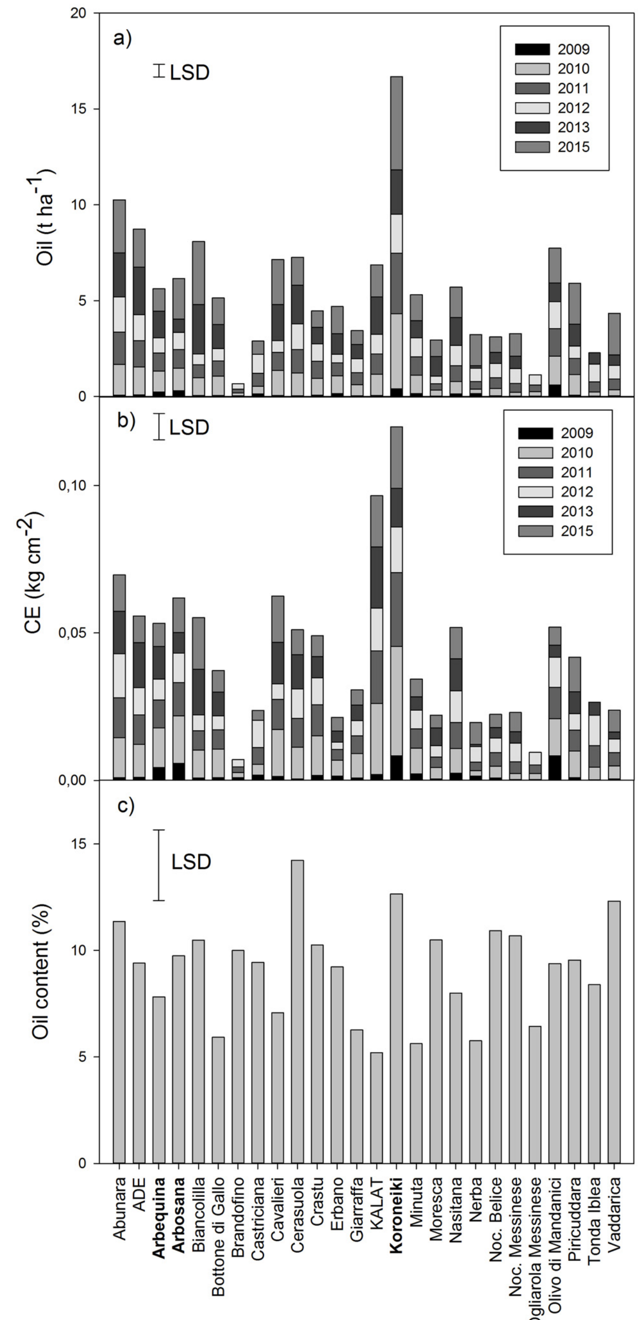


**Fig. 3.** Cumulative oil yield per ha (t/ha, fig. a). Oil crop efficiency (CE, Kg of oil/cm$^2$ of TCSA, b) and fruit oil content (%) from the third (2009) to the ninth (2015) year after planting the 23 Sicilian genotypes in a high-density system (1140 trees/ha) compared to the international varieties 'Arbequina', 'Arbosana' and 'Koroneiki'. LSD = least significant difference; d.f. = 182; $P < 0.001$.

Sicilian cultivars produced yield comparable to that of the international cultivars 'Arbequina' and 'Arbosana' at about 8–10 t/ha. In 2013 (Fig. 1e), 'ADE' had the highest production of 26 t/ha, followed by the 'Biancolilla' at 24 t/ha, 'KALAT' at 22 t/ha, 'Abunara' at 20 t/ha and 'Bottone di Gallo' at 19 t/ha while 'Koroneiki' and 'Arbequina' produced a collective average of 18 t/ha. In the final experimental year, 2015 (Fig. 1f), 'Koroneiki' and 'Biancolilla' had the highest yields at 38 and 31 t/ha, respectively. All the other cultivars 'Abunara', 'Cavalieri', 'Piricuddara', 'Arbosana', 'Bottone di Gallo' and 'ADE' followed with average yields of 21 t/ha. The other eight Sicilian genotypes had higher yields per ha than 'Arbequina' which produced 15 t/ha. Over the 6 experimental years, 2009–2015, (Fig. 2a), the control 'Koroneiki' was the most productive cultivar with 131 t/ha in six years while six of the 23 Sicilian cultivars/genotypes had cumulative yields per ha that were significantly higher than the control 'Arbequina' which produced 71 t/ha. The 'ADE' selection produced 93 t/ha, 'Abunara' 90 t/ha, 'Bottone di Gallo' 80 t/ha, 'KALAT' 80 t/ha, 'Biancolilla' 77 t/ha, and 'Olivo di Mandanici' 72 t/ha.

### *3.2. Alternate bearing and crop efficiency*

The cultivars 'Crastu' and 'Giarraffa' had the lowest ABI at 0.01 and 0.03, respectively, followed by 'Minuta' and 'Abunara' at 0.07, 'Cerasuola', 'KALAT', 'ADE' and 'Nasitana' at 0.11, and 'Castriciana' and 'Nerba' at 0.61 and 0.51, respectively, had the highest alternate bearing indexes (Fig. 2a). The selection 'KALAT' had the highest crop efficiency at 0.22 $kg/cm^2$, followed by 'Koroneiki' at 0.17 $kg/cm^2$, 'Arbequina' at 0.13 $kg/cm^2$ and 'Cavalieri' at 0.12 $kg/cm^2$ (Fig. 2b).

### 3.3. Oil yield

As in most SHD plantings the 'Koroneiki' cultivar again produced the highest oil yields, exceeding all the other genotypes (Fig. 3a). Among the Sicilian accessions 'Abunara' produced the highest oil yield, followed by 'ADE', 'Biancolilla' and 'Olivo di Mandanici'. Fruit yields were similar. Interestingly, two Sicilian cultivars, 'Cavalieri' and 'Cerasuola' did not have high fruit yields but did produce high oil yields. Koroneiki was the most efficient oil producer at 0.12 $kg/cm^2$ followed by KALAT, 0.10 $kg/cm^2$, and 'Abunara', 'Cavalieri', 'Arbosana', 'ADE', 'Biancolilla' and 'Arbequina' (Fig. 3b). The 'Cerasuola', 'Koroneiki' and 'Vaddarica' cultivars had the highest fruit oil content, over 12%, followed by 'Abunara', 'Biancolilla', 'Moresca', 'Nocellara del Belice' and 'Nocellara Messinese', all higher than 10%. The 'Bottone di Gallo', 'KALAT', 'Minuta' and 'Nerba' cultivars all produced less than 6% oil.

### 3.4. Vegetative growth

'Olivo di Mandanici' was the most vigorous cultivar with the highest TCSA value of 266 $cm^2$ followed by 'Erbano' at 262 $cm^2$ and 'Vaddarica' at 254 $cm^2$ (Fig. 4). The TCSA values of 'Minuta', 'Koroneiki', 'Nerba', 'Abunara' and 'ADE' ranged between 190 and 226 $cm^2$ (Fig. 4). The 'KALAT' selection was the least vigorous at 90 $cm^2$, followed by 'Crastu', 'Giarraffa', 'Arbequina' and 'Nasitana', which ranged from 90 to 134 $cm^2$).

Tree heights for the international cultivars averaged approximately 2 m in the fourth YAP and were significantly lower than that for most of the Sicilian cultivars with the exception of 'KALAT' and 'Giarraffa' (Fig. 5a). All the cultivars, even those with taller canopies, 'Erbano', 'Minuta', 'Cerasuola', 'Nerba', 'Olivo di Mandanici', were harvestable by the straddle machine harvester. The 'Arbosana' at 7.5 $m^3$ had the smallest canopy volume (Fig. 5b) followed by 'Ogliarola Messinese', 'Giarraffa', 'Santagatese', 'KALAT' and 'Olivo di Mandanici' at approximately 8 $m^3$. The 'Nerba' and 'Erbano' averaging over 20 $m^3$ followed by 'Bottone di Gallo', 'ADE', 'Moresca' and 'Minuta', which ranged from 16 to 18 $m^3$, had the largest canopies.

### 3.5. Olive oil quality

The free acidity and peroxide values were significantly lower than the standards required for classification as extra virgin by the International Olive Oil Council (IOOC). The oleic acid, C18:1, concentration (Table 2) varied from 67% in 'Moresca' to a maximum of 82% in 'Cerasuola'. The average value among all the cultivars/genotypes was 74%. The 'Tonda Iblea' and 'Nocellara Messinese' cultivars had higher oleic acid contents, above 80%, while 'Castriciana', 'Minuta', 'KALAT', 'Piricuddara' ranged between 78 and 79%. Palmitoleic acid, C16:1, varied from 0.15% in 'Cerasuola' to 1.02% in 'Moresca' while the other two genotypes, 'Tonda Iblea' and 'Nocellara Messinese' were below the 0.3% limit established for Extra Virgin Olive Oils (EVOOs). At 7.8% 'Cerasuola' produced lowest level of palmitic acid, C16:0, but was still above the IOOC minimum threshold. The highest percentages were observed in 'Arbequina', 'Vaddarica' and 'Moresca' at 14–15%. The average value for all the varieties was 12%. Stearic acid, C18:0, content was between 0.87% for 'Cavalieri' and 1.63% for 'Castriciana' and 'Nocellara Messinese'. None of the varieties exceeded the linoleic acid, C18:2, values established for designation as EVOOs. The highest percentages were observed in 'Moresca' and 'Biancolilla', at 14 and 12%, respectively. The 'Nocellara Messinese' cultivar had the lowest at 7.19%. The level of linolenic acid, 18:3, was within the range allowed for the EVOOs in all the experimental genotypes ranging between 0.09% for 'Vaddarica' and 0.16% for 'Biancolilla'. The olive oils also contained low amounts of arachidic acid, C20:0, with an average value of 0.35% and traces of gadoleic acid, C20:1, which averaged 0.05%. The cultivar 'Moresca' had the lowest ratios of UFAs:SAFs, at <5, and MUFAs:PUFAs, at <6. The 'Cerasuola' cultivar had a ratio of 10 UFAs/SAFs and Nocellara Messinese' had a ratio of 12.2 MUFAs/PUFAs (Table 3). The total phenol content of the oils ranged from a minimum of 114 ppm in 'Minuta' to a maximum of 487 ppm in 'Nocellara Messinese', with an average value of 250 ppm (Fig. 6). Values for this component above 300 ppm were also recorded in 'Erbano' and 'Cerasuola'. Table 4 lists the genotypes distinguished by a specific characteristic; for example, high yields for 'Abunara' and 'ADE', good oil quality for 'Cerasuola' and 'Piricuddara', or low vigor in 'KALAT'.

## 4. Discussion

These results confirm earlier reports from multiple regions; the Spanish 'Arbequina' and 'Arbosana' cultivars are the most productive cultivars in SHD orchards (Camposeo and Godini, 2010; Caruso et al., 2014a; León et al., 2006; Marra et al., 2016). However, in this trial the Greek cultivar 'Koroneiki' had higher average yield per ha than previously reported (Díez et al., 2016; Tous et al., 2002, 2004, 2011). Our experimental area is characterized by a long growing season which enhanced tree vegetative growth and vigor, note the high TCSA values (Fig. 4), which enhanced productivity (León et al., 2006). This result confirms the strong effect of the growing area and climatic condition on olive tree performance (Marino et al., 2016) and the suitability of this area for the SHD orchards (Caruso et al., 2012). Considering that the average yearly productivity observed in this trial for 'Arbequina', 13.6 t/ha, was comparable to that of commercial orchards located in Spanish area of origin (Camposeo and Godini, 2010; De la Rosa et al., 2007; León et al., 2006; Tous et al., 2003, 2011) we used this cultivar as the reference for evaluating the potential productivity of the selected genotypes studied.

The majority of the genotypes produced fruits at three years confirming earlier reports (Camposeo et al., 2008; Camposeo and Godini, 2010; De la Rosa et al., 2007; Godini et al., 2006a; Larbi et al., 2011; Pastor et al., 2007). The suitability of 'Koroneiki', 'Arbequina' and 'Arbosana' for SHD orchards was reconfirmed as these three cultivars had the most consistent crop in the third YAP relative to most of the Sicilian genotypes with the exception of 'Olivo di Mandanici' and 'Minuta'. Interestingly, many of the local cultivars/genotypes, particularly 'Abunara' and 'ADE' had higher or similar cumulative fruit and oil yields relative to 'Arbequina' (Fig. 2a, Fig. 3). 'KALAT' had higher yields than the two Spanish cultivars but lower vigor. The TCSA at the 9th YAP was only 90 $cm^2$, the lowest among the all genotypes and lower than that of 'Arbosana' (Fig. 4). Generally, 'KALAT' selection was less vigorous than the three standard cultivar controls. This high yield and low vigor resulted in significantly higher CE values relative to all the Sicilian and standard genotypes analyzed, averaging 0.21 $kg/cm^2$. This is surprising not only because is so much higher than previously reported for SHD systems (Caruso et al., 2014a) but because it was consistent through the trial with an ABI of only 0.11. In previous studies with 'Arbequina', an early CE of 0.22 $kg/cm^2$ appeared unsustainable as it affected the following year's production (Marra et al., 2016; Tous et al., 2011). Unfortunately, the 'KALAT' oil had a low polyphenol content. However, its low vigor still makes 'KALAT' a good candidate for inclusion in plant improvement programs. The productivity of a cultivar is an interaction of multiple

**Table 2**
Fatty acid composition (%) of virgin olive oils from the 21 Sicilian genotypes planted in a high-density system (1140 t/ha) compared to the international varieties (in bold) 'Arbequina', 'Arbosana' and 'Koroneiki'. Each data is the average of three years (2012, 2013, 2015). The data for the cultivars 'Brandofino' and 'Ogliarola Messinese' are not reported they produced fruit only in 2012. Data are reported as mean ± SE.

| Genotypes | C 16:0 | C 16:1 | C 18:0 | C 18:1 | C 18:2 | C 18:3 | C 20:0 | C 20:1 |
|---|---|---|---|---|---|---|---|---|
| Abunara | 11.16 ± 0.66 | 0.32 ± 0.05 | 1.10 ± 0.26 | 75.76 ± 0.98 | 11.08 ± 0.67 | 0.16 ± 0.02 | 0.25 ± 0.09 | 0.07 ± 0.01 |
| **Arbequina** | 13.86 ± 1.59 | 0.92 ± 0.32 | 1.03 ± 0.24 | 72.39 ± 2.56 | 11.22 ± 0.99 | 0.14 ± 0.01 | 0.33 ± 0.16 | 0.05 ± 0.01 |
| **Arbosana** | 12.32 ± 1.14 | 0.89 ± 0.26 | 1.19 ± 0.10 | 75.05 ± 3.33 | 9.90 ± 2.14 | 0.15 ± 0.02 | 0.44 ± 0.10 | 0.07 ± 0.00 |
| Biancolilla | 12.87 ± 1.28 | 0.79 ± 0.38 | 1.29 ± 0.39 | 72.10 ± 2.29 | 12.26 ± 1.09 | 0.16 ± 0.02 | 0.35 ± 0.17 | 0.06 ± 0.01 |
| Bottone di gallo | 11.87 ± 1.72 | 0.47 ± 0.21 | 0.88 ± 0.07 | 74.04 ± 2.30 | 12.14 ± 0.59 | 0.15 ± 0.03 | 0.26 ± 0.12 | 0.07 ± 0.02 |
| KALAT | 11.00 ± 2.22 | 0.50 ± 0.28 | 1.05 ± 0.15 | 78.07 ± 3.47 | 8.90 ± 1.17 | 0.13 ± 0.02 | 0.28 ± 0.14 | 0.06 ± 0.01 |
| Castriciana | 10.71 ± 0.05 | 0.34 ± 0.03 | 1.63 ± 0.26 | 77.65 ± 0.46 | 9.02 ± 0.82 | 0.11 ± 0.00 | 0.49 ± 0.14 | 0.04 ± 0.01 |
| Cavalieri | 12.34 ± 0.53 | 0.55 ± 0.13 | 0.87 ± 0.18 | 76.84 ± 0.77 | 8.84 ± 0.41 | 0.15 ± 0.00 | 0.29 ± 0.13 | 0.06 ± 0.02 |
| Cerasuola | 7.84 ± 1.06 | 0.15 ± 0.08 | 1.25 ± 0.23 | 82.35 ± 2.08 | 7.93 ± 0.76 | 0.11 ± 0.01 | 0.31 ± 0.16 | 0.06 ± 0.01 |
| Crastu | 13.28 ± 0.24 | 0.58 ± 0.12 | 1.07 ± 0.19 | 75.65 ± 0.51 | 8.87 ± 0.78 | 0.13 ± 0.00 | 0.31 ± 0.15 | 0.04 ± 0.01 |
| Erbano | 12.66 ± 0.54 | 0.49 ± 0.00 | 1.22 ± 0.01 | 73.95 ± 0.03 | 11.01 ± 0.72 | 0.12 ± 0.01 | 0.51 ± 0.15 | 0.05 ± 0.01 |
| Giarraffa | 12.59 ± 2.52 | 0.75 ± 0.42 | 0.96 ± 0.15 | 73.29 ± 5.02 | 11.71 ± 1.97 | 0.14 ± 0.01 | 0.41 ± 0.24 | 0.06 ± 0.02 |
| **Koroneiki** | 12.31 ± 1.83 | 0.43 ± 0.13 | 1.08 ± 0.25 | 76.67 ± 3.44 | 9.00 ± 1.30 | 0.12 ± 0.01 | 0.31 ± 0.19 | 0.04 ± 0.01 |
| Minuta | 10.64 ± 2.44 | 0.63 ± 0.24 | 1.11 ± 0.15 | 77.88 ± 2.12 | 9.17 ± 1.15 | 0.13 ± 0.02 | 0.31 ± 0.18 | 0.05 ± 0.01 |
| Moresca | 15.31 ± 0.01 | 1.02 ± 0.04 | 1.22 ± 0.06 | 67.94 ± 1.05 | 13.84 ± 1.03 | 0.10 ± 0.02 | 0.52 ± 0.16 | 0.05 ± 0.01 |
| Nasitana | 12.66 ± 0.99 | 0.81 ± 0.18 | 1.05 ± 0.28 | 76.54 ± 3.12 | 8.44 ± 2.42 | 0.14 ± 0.02 | 0.30 ± 0.16 | 0.04 ± 0.01 |
| Nerba | 12.75 ± 1.38 | 0.85 ± 0.33 | 0.99 ± 0.34 | 74.89 ± 4.14 | 9.98 ± 2.96 | 0.13 ± 0.03 | 0.31 ± 0.19 | 0.04 ± 0.01 |
| Nocellara Belice | 11.60 ± 0.60 | 0.48 ± 0.08 | 1.53 ± 0.50 | 74.39 ± 1.16 | 11.36 ± 1.21 | 0.15 ± 0.01 | 0.39 ± 0.20 | 0.06 ± 0.01 |
| ADE | 10.43 ± 1.39 | 0.39 ± 0.16 | 1.16 ± 0.25 | 76.88 ± 2.51 | 10.57 ± 0.69 | 0.12 ± 0.01 | 0.37 ± 0.21 | 0.05 ± 0.01 |
| Nocellara messinese | 9.63 ± 1.17 | 0.29 ± 0.11 | 1.54 ± 0.07 | 80.82 ± 2.61 | 7.19 ± 1.46 | 0.14 ± 0.01 | 0.35 ± 0.05 | 0.05 ± 0.01 |
| Olivo di Mandanici | 12.16 ± 1.17 | 0.56 ± 0.13 | 1.22 ± 0.28 | 74.24 ± 2.94 | 11.15 ± 2.36 | 0.15 ± 0.02 | 0.34 ± 0.18 | 0.06 ± 0.01 |
| Piricuddara | 9.99 ± 0.40 | 0.34 ± 0.05 | 0.95 ± 0.25 | 78.82 ± 1.24 | 9.31 ± 1.15 | 0.14 ± 0.03 | 0.30 ± 0.17 | 0.05 ± 0.00 |
| Tonda Iblea | 9.68 ± 1.68 | 0.23 ± 0.09 | 0.92 ± 0.13 | 80.23 ± 2.03 | 8.61 ± 0.08 | 0.12 ± 0.00 | 0.15 ± 0.05 | 0.07 ± 0.00 |
| Vaddarica | 14.52 ± 0.77 | 0.97 ± 0.27 | 1.22 ± 0.01 | 71.22 ± 1.98 | 11.49 ± 0.85 | 0.09 ± 0.01 | 0.43 ± 0.11 | 0.05 ± 0.01 |
| **Average** | 11.84 ± 0.30 | 0.57 ± 0.04 | 1.15 ± 0.05 | 75.74 ± 0.56 | 10.12 ± 0.30 | 0.13 ± 0.00 | 0.35 ± 0.03 | 0.05 ± 0.00 |
| **Norm (IOC. 2008)** | 7.5–20 | 0.3–3.5 | 0.5–5 | 55–83 | 3.5–21 | ≤1 | ≤0.6 | |

**Table 3**
Calculated ratios between unsaturated fatty acid (UFAs) and saturated fatty acid (SAFs), monounsaturated fatty acids (MUFAs) and polyunsaturated fatty acids (PUFAs), oleic acid (C18:1) and linoleic acid (C18:2) of virgin olive oils from the 23 Sicilian genotypes planted in a high-density system (1140 t/ha) compared to the international varieties (in bold) 'Arbequina', 'Arbosana' and 'Koroneiki'. Each data is the average of three years (2012, 2013, 2015). The data for the cultivars 'Brandofino' and 'Ogliarola Messinese' are not reported because they produced fruit only in 2012. Data are reported as mean ± SE.

| Cultivar | UFAs | SAFs | MUFAs | PUFAs | UFAs/SAFs | MUFAs/PUFAs | C18:1/C18:2 |
|---|---|---|---|---|---|---|---|
| Abunara | 87.40 ± 0.88 | 12.50 ± 0.98 | 76.15 ± 0.93 | 11.24 ± 0.66 | 7.09 ± 0.66 | 6.82 ± 0.43 | 6.89 ± 0.45 |
| ADE | 88.00 ± 1.81 | 11.96 ± 1.85 | 77.32 ± 2.37 | 10.68 ± 0.68 | 7.78 ± 1.36 | 7.33 ± 0.71 | 7.37 ± 0.75 |
| **Arbequina** | 84.72 ± 1.78 | 15.22 ± 1.81 | 73.37 ± 2.32 | 11.35 ± 1.00 | 5.74 ± 0.72 | 6.60 ± 0.81 | 6.59 ± 0.82 |
| **Arbosana** | 86.06 ± 0.94 | 13.95 ± 0.94 | 76.01 ± 3.06 | 10.05 ± 2.12 | 6.24 ± 0.49 | 8.49 ± 2.25 | 8.57 ± 2.35 |
| Biancolilla | 85.38 ± 1.15 | 14.51 ± 1.23 | 72.96 ± 1.92 | 12.43 ± 1.09 | 5.98 ± 0.56 | 6.00 ± 0.71 | 6.01 ± 0.74 |
| Bottone di gallo | 86.88 ± 1.75 | 13.02 ± 1.79 | 74.59 ± 2.10 | 12.29 ± 0.61 | 6.94 ± 0.96 | 6.11 ± 0.46 | 6.14 ± 0.47 |
| Castriciana | 87.17 ± 0.34 | 12.83 ± 0.35 | 78.04 ± 0.48 | 9.13 ± 0.82 | 6.81 ± 0.21 | 8.70 ± 0.84 | 8.76 ± 0.86 |
| Cavalieri | 86.43 ± 0.32 | 13.51 ± 0.26 | 77.44 ± 0.66 | 8.99 ± 0.41 | 6.40 ± 0.15 | 8.66 ± 0.48 | 8.74 ± 0.50 |
| Cerasuola | 90.60 ± 1.24 | 9.40 ± 1.24 | 82.56 ± 2.01 | 8.04 ± 0.77 | 10.06 ± 1.57 | 10.52 ± 1.32 | 10.65 ± 1.35 |
| Crastu | 85.29 ± 0.38 | 14.66 ± 0.41 | 76.28 ± 0.58 | 9.01 ± 0.78 | 5.83 ± 0.18 | 8.60 ± 0.76 | 8.66 ± 0.78 |
| Erbano | 85.62 ± 0.68 | 14.39 ± 0.67 | 74.49 ± 0.03 | 11.13 ± 0.70 | 5.98 ± 0.33 | 6.75 ± 0.43 | 6.78 ± 0.45 |
| Giarraffa | 85.96 ± 2.71 | 13.97 ± 2.78 | 74.10 ± 4.66 | 11.85 ± 1.95 | 6.92 ± 1.92 | 6.84 ± 1.78 | 6.88 ± 1.85 |
| KALAT | 87.66 ± 2.50 | 12.33 ± 2.51 | 78.63 ± 3.23 | 9.03 ± 1.15 | 7.89 ± 1.95 | 9.08 ± 1.53 | 9.17 ± 1.60 |
| **Koroneiki** | 86.26 ± 2.06 | 13.70 ± 2.08 | 77.15 ± 3.32 | 9.12 ± 1.31 | 6.60 ± 1.00 | 8.90 ± 1.53 | 8.97 ± 1.56 |
| Minuta | 87.86 ± 2.73 | 12.06 ± 2.74 | 78.56 ± 1.89 | 9.30 ± 1.13 | 8.20 ± 2.05 | 8.65 ± 0.84 | 8.71 ± 0.88 |
| Moresca | 82.94 ± 0.09 | 17.06 ± 0.09 | 69.01 ± 1.10 | 13.93 ± 1.01 | 4.86 ± 0.03 | 5.02 ± 0.45 | 4.98 ± 0.45 |
| Nasitana | 85.97 ± 0.59 | 14.01 ± 0.58 | 77.39 ± 2.94 | 8.58 ± 2.41 | 6.16 ± 0.31 | 11.18 ± 4.01 | 11.40 ± 4.24 |
| Nerba | 85.88 ± 1.16 | 14.05 ± 1.20 | 75.77 ± 3.81 | 10.11 ± 2.93 | 6.21 ± 0.57 | 9.92 ± 4.25 | 10.12 ± 4.48 |
| Nocellara Belice | 86.44 ± 0.33 | 13.53 ± 0.32 | 74.93 ± 1.11 | 11.51 ± 1.22 | 6.40 ± 0.18 | 6.69 ± 0.87 | 6.73 ± 0.88 |
| Nocellara messinese | 88.49 ± 1.04 | 11.51 ± 1.04 | 81.16 ± 2.50 | 7.33 ± 1.46 | 7.83 ± 0.81 | 12.22 ± 2.94 | 12.48 ± 3.09 |
| Olivo di Mandanici | 86.16 ± 1.31 | 13.72 ± 1.42 | 74.86 ± 2.86 | 11.31 ± 2.34 | 6.46 ± 0.85 | 7.37 ± 1.82 | 7.45 ± 1.88 |
| Piricuddara | 88.66 ± 0.72 | 11.24 ± 0.81 | 79.20 ± 1.23 | 9.46 ± 1.13 | 7.98 ± 0.64 | 8.62 ± 1.02 | 8.73 ± 1.06 |
| Tonda Iblea | 89.26 ± 1.86 | 10.74 ± 1.87 | 80.53 ± 1.94 | 8.73 ± 0.08 | 8.93 ± 1.81 | 9.23 ± 0.31 | 9.33 ± 0.32 |
| Vaddarica | 83.82 ± 0.88 | 16.17 ± 0.89 | 72.24 ± 1.72 | 11.58 ± 0.84 | 5.22 ± 0.34 | 6.33 ± 0.61 | 6.29 ± 0.64 |
| **Average** | 86.62 ± 0.31 | 13.33 ± 0.32 | 76.36 ± 0.52 | 10.26 ± 0.30 | 6.85 ± 0.22 | 8.11 ± 0.35 | 8.18 ± 0.36 |

**Table 4**
Main characteristics of the five best performing genotypes.

| Name | Type | Oil yield | Vigor | Oil quality | Description |
|---|---|---|---|---|---|
| Abunara | Minor cv | Very high | High | Medium high | Good quality, strong production but vigorous tree |
| ADE | Selection | Very high | High | Medium | Medium quality, very high productivity but vigorous tree |
| KALAT | Selection | Medium high | Very low | Medium | Medium quality, good yield and very low vigor |
| Cerasuola | Main cv | High | Medium | Very high | The best quality profile, high yield and medium vigor |
| Piricuddara | Minor cv | Medium high | Medium | High | Good quality and production, medium vigor |

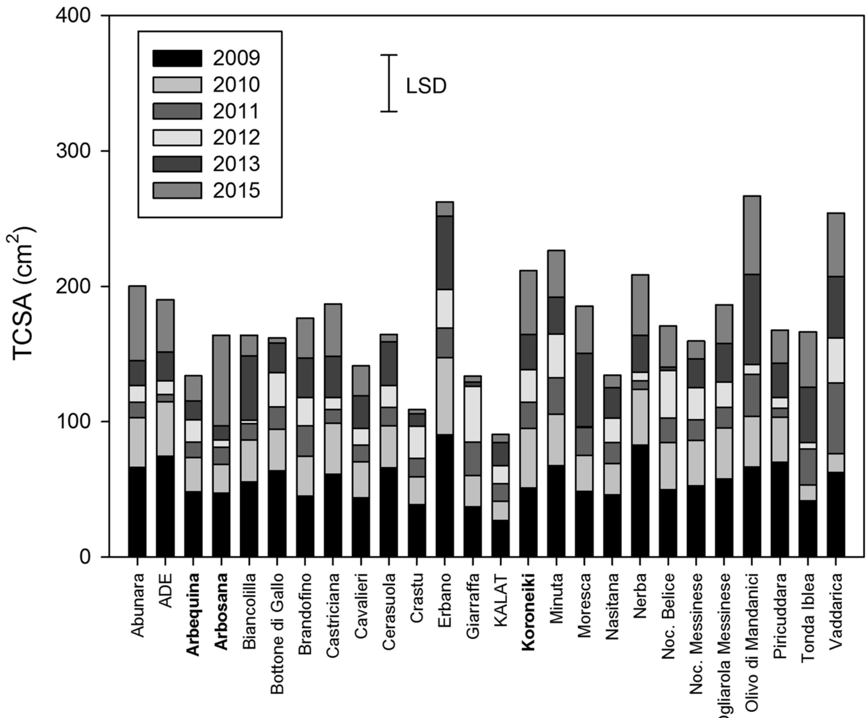


**Fig. 4.** Trunk cross section area (TCSA, $cm^2$) from the third (2009) to the ninth (2015) year after planting the 23 Sicilian genotypes in a high-density system (1140 trees/ha) compared to the international varieties 'Arbequina', 'Arbosana' and 'Koroneiki'. LSD = least significant difference; d.f. = 182; $P < 0.001$.

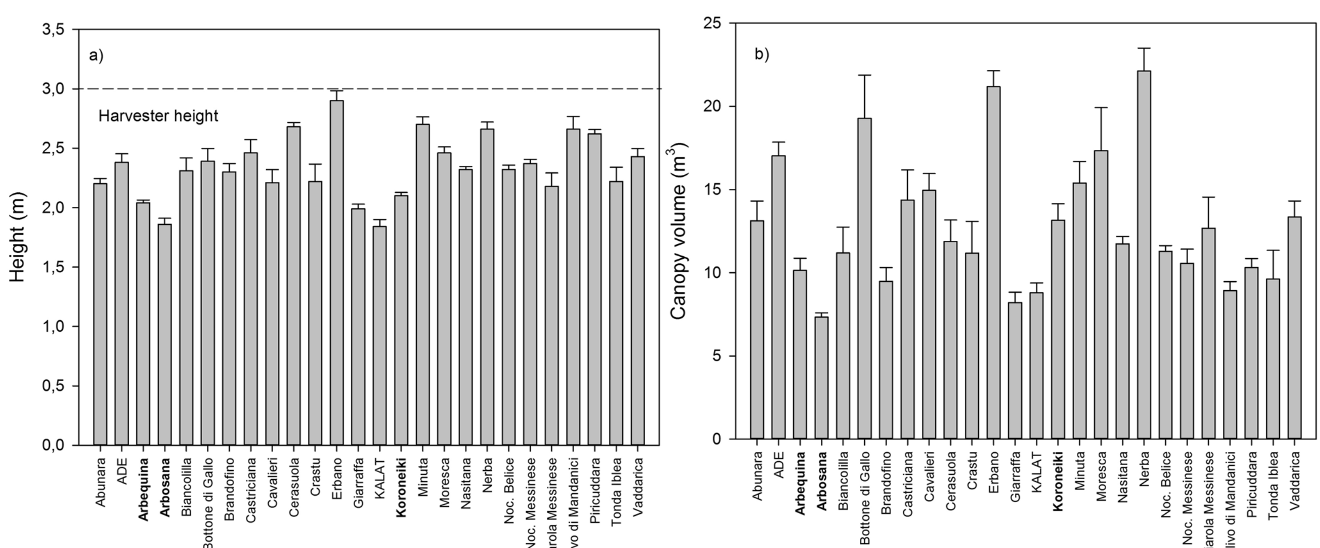


**Fig. 5.** Tree height (a) and canopy volume (b) at the end of fourth year after planting (2010) the 23 Sicilian genotypes in a high-density system (1140 trees/ha) compared to the international varieties 'Arbequina', 'Arbosana' and 'Koroneiki'. LSD = least significant difference; d.f. = 182; $P < 0.001$.

factors: genetics, management and environment (Di Vaio et al., 2013). Some genotypes, evaluated outside their area of origin, do not fully express their productive potential. For this reason, some of the low- or non-productive cultivars, like 'Tonda Iblea', from higher altitudes may not have fully expressed their potential in this experiment. Therefore, repeating the experiment elsewhere may produce different results.

Cultivars suited for SHD production must be high quality to be considered as functional foods by the EVOOs (Stark and Madar, 2002). The oils evaluated in the present experiment had very high oleic acid levels and good monounsaturated (MUFAs) to polyunsaturated fatty acids (PUFAs) ratios, the parameter that slows penetration of fatty acids into arterial walls (Charbonnier, 1982). The oleic acid levels are better than those reported for 'Arbequina' and 'Koroneiki' grown in Tunisia (Allalout et al., 2011; Dabbou et al., 2011; Guerfel et al., 2012; Zarrouk et al., 2008), Spain (León et al., 2006) and Italy (Camposeo et al., 2010). This result is particularly interesting considering the more southern warmer climate location of this trial as higher oleic acid levels are generally produced in more northern and colder climates (Civantos et al., 1992; Tous et al., 1997). The Sicilian cultivar 'Cerasuola' has a particularly healthy chemical profile with high oleic acid and phenols

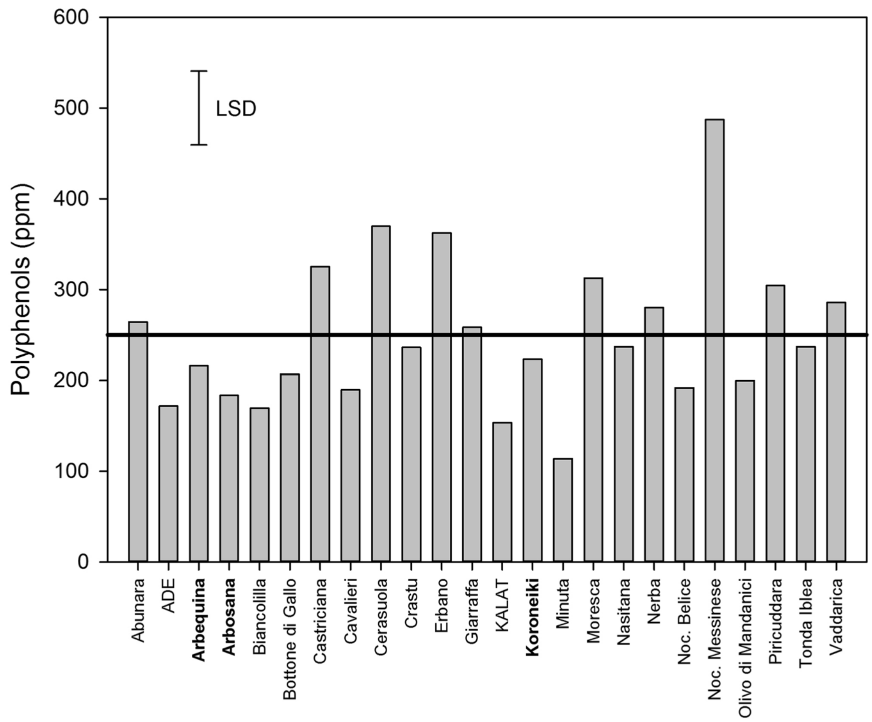


**Fig. 6.** Polyphenols content of virgin olive oils from the 23 Sicilian genotypes planted in a high-density system (1140 trees/ha) compared to the international varieties (Bold) 'Arbequina', 'Arbosana' and 'Koroneiki'. Each data point is the average of three years (2012, 2013, 2015). LSD = least significant difference; d.f. = 48; $P < 0.001$. The cultivar 'Brandofino' e 'Ogliarola Messinese' are not reported because they did not produce fruit. The dotted horizontal line shows the average values of all the genotypes.

contents. The oil from this cultivar was the only one in this trial to possess the hydroxytyrosol and secoiridoid derivatives such as 3,4-DHPEA-EDA, 3,4 DHPEA-EA, p-HPEA-DEA and p-HPEA-EA necessary for authorization under Regulation EC 1924/2006 to label and market an oil in the EU as a healthy product that can claim the beneficial effects of phenols in protecting blood lipids from oxidative stress. Additionally, oils produced by 'Cerasuola', 'Nasitana' and 'Nocellara messinese' had C18:1/C18:2 and MUFAs/PUFAs ratios, which are positively correlated with oil stability and health (Salvador et al., 1999), higher than those detected in other cultivars. The oils from the 'Nocellara Messinese' and 'Piricuddara' accessions also had high oleic acid and very high phenols content, particularly the cultivar 'Nocellara Messinese' with 432 ppm of total phenols. These two genotypes, had hydroxytyrosol and secoiridoids derivatives contents just slightly lower 5 mg/20 g threshold, suggesting that, with specific management, these oils could also earn healthy food labels. Both 'Cerasuola' and 'Piricuddara' had very high quality oils as well as average yields per ha approaching those of 'Arbosana' and just slightly lower than those of 'Arbequina'. Among the most productive genotypes 'Abunara' had the best oil composition with 342 ppm phenols and 74% oleic acid.

## 5. Conclusions

The results reported here confirm the importance of preserving and evaluating local genetic resources for improving olive oil quality and productivity (Camposeo and Godini, 2010). 'Abunara' and 'ADE' were the most productive genotypes evaluated. The 'Abunara' cultivar also produced good quality oil. The 'Cerasuola' and 'Piricuddara' cultivars were also highly productive and produced high quality oils. The 'KALAT' selection had outstanding productivity paired with very low vigor. All these genotypes offer advantages for the SHD olive growers. Cultivars with different ripening times would enable growers to extend the harvesting period decreasing oil quality reduction due to harvesting delays. Diversification would also expand markets. Using the best cultivars identified in this trial the SHD olive grower could offer the consumer both a low-price medium-quality oil and high quality oil at reduced prices relative to hand harvested orchard.

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