Emirates Journal of Food and Agriculture. 2018. 30(7): 592-603
doi: 10.9755/ejfa.2018.v30.i7.1742
http://www.ejfa.me/

REGULAR ARTICLE

Pre-and post-harvest factors and their impact on oil composition and quality of olive fruit

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ABSTRACT

Olive fruit and its oil are in great demand due to its nutritional value, which can be influenced by the pre-and post-harvest factors. The pre- and post-harvest factors are discussed in this article in an effort to recognize as being and investigate the ultimate effect of these factors on the olive fruit and its oil composition. Genetic, agronomic and environmental factors influence olive fruits and olive oil composition. The olive cultivar influences fruit weight, olive oil content, fatty acids, peroxide value, esters, volatile compounds and fatty alcohol content. Chlorophyll content, carotenoids, flavor and volatile compounds vary depending upon geographical area of origin. Environmental conditions have an effect on enzymes, oil composition, fatty acids, microbial activity, esters, flowering, growth and development, ripening rate, insect activity and susceptibility or resistance to diseases. Tree age has an impact on phenol content of olive oil. The boron, nitrogen, potassium, salinity and zinc treatments have an influence on the olive fruit and its oil composition. In addition, the ripening degree, harvesting time has enforcement on olive oil content. Leaf removal and washing of the fruit promote the purity of the olive oil for both chemical and sensorial aspects. A not prolonged fruit crushing together with a not prolonged paste malaxation at a temperature below 27 °C increase the sensory and physicochemical qualities of olive oil. Inappropriate oil extraction promotes the off-flavors in the olive oil. Dark storage helps to retain the chemical and sensorial olive oil quality. The oil quality degrades toward the inside of cooking temperature.

Keywords: Olive fruit; *Olea europaea*; Fruit ripening; Fruit storage; Cooking

INTRODUCTION

Olive fruit (*Olea europaea* L.) is a drupe and contains water (30-40%), oil (6-25%) and solids (45-60%). Many factors were proved to influence the olive fruit and the olive oil composition. The cultivar, harvest year, irrigation or rain-fed condition and cultivation system(s) all serve to influence the olive biometric parameters and consequently, the choice to use an olive cultivar for oil extraction or as a table olive or for dual use (table and oil). The commercial value of drupes is related to their pulp/stone ratio and a 5:1 ratio is considerably as acceptable. The value of olives increases with the increase of this ratio. Olives for table use are required to have a pulp/stone ratio higher than 5 whereas cultivars producing olive fruits with a ratio lower than 5 are usually used for oil extraction. Olive fruits are classified in relation to their size: 'large size' if the fruit weight is higher than 5 g; 'medium size' if the weight is ranging between 5 and 3 g; 'small size' if the weight is lower than 3 g (IOC, 2018). The olive oil physicochemical parameters are also influenced by genetic, agronomic and environmental factors (Patumi et al., 2002; Pinheiro and Silva, 2005; Aganchich et al., 2008; Rosati et al., 2009; Peres et al., 2011; Piscopo et al., 2016; Sorrentino et al., 2016; Giuffrè, 2017). Olive oil is mainly composed of glycerides (about 98.5-99.0%) i.e. free fatty acids, tri-, di- and monoglycerides; the rest (1.0-1.5%) is composed by the so called minor components: sterols, fatty alcohols, triterpene alcohols, hydrocarbons (n-alkanes, n-alkenes, squalene), pigments (chlorophylls, carotenes), waxes, phenols, tocopherols and volatiles (Servili et al., 2004). Oleic acid (55.0-83.0%), palmitic acid (7.50-20.0%), and linoleic acid (2.50-21.0%) comprises the main fatty acids contained in olive oil (IOC, 2015). Hydroxytyrosol, secoiridoids and tyrosol is the main components of olive oil phenolic compounds (Santos et al., 2013). Phenolic and ortho-diphenolic compounds as well as fatty acid composition influence the antioxidant activity of olive oils (Visioli et al., 2002).

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Received: 20 March 2018; **Accepted:** 30 June 2018

Table 1: A comparison between Italy and korea republic on the basis of trade (import and export) in 2013

Serial number	Country name	Item	Trade	Quantity (tones)	Values (1000USD)
1	Italy	Oil, olive residues	Import Export	23974 40975	48666 105343
		Oil, olive, virgin	Import Export	457419 344042	1576935 1720608
		olives	Import Export	7072 2496	14494 5751
		Olives preserved	Import Export	70693 22351	113644 70715
2	Korea Republic	Oil, olive residues	Import Export	1973 2	5779 7
		Oil, olive, virgin	Import Export	10135 189	43467 813
		olives	Import Export	0 0	0 0
		Olives preserved	Import Export	2540 0	4312 0

Source: FAOSTAT. http://faostat.fao.org, Food and Agriculture Organization (FAO) of the United Nations

In fact, olive fruit and its oil demand are increasing day by day due, mainly to its nutritional value. According to FAO (FAOSTAT, 2016), the olive harvested area consisted of 10,650 thousand hectares, the production was 19,267 thousand tonnes and the yield was 18,091 hectogram/ hectare (calculated data), worldwide. Although the olive harvested area, production and yield data of Italy is available in FAOSTAT, it has lacked in the Korea Republic because the climatic condition may disfavour the growth of olives, and the production of olive fruit, oil and related products. There is a huge difference between Italy and Korea Republic with regard to the olive and its oil trade (Table 1).

There are several pre-harvest factors (cultivar, growing area, environmental condition, soil, tree age, treatment, irrigation, fruit ripening, harvest time, maturity and fruit picking) and post-harvest factors (fruit storage, leaf removal and fruit washing, fruit crushing, paste malaxation, oil extraction systems, oil storage and cooking) to be considered. In this review, we survey recent research on pre-and post-harvest factors and their respective effects on olive fruit and its oil composition.

PRE-HARVEST FACTORS

The pre-harvest factors are discussed in this section. These are cultivar, growing area, environmental condition, soil, tree age, treatment, irrigation, fruit ripening, harvest time, maturity and fruit picking.

Cultivar/Genotype

The olive cultivar influences the physico-chemico-sensorial properties of the oil. The olive oil acidity, olive oil content and peroxide value increase in the Nabali, Improved Nabali and Abo-shoka cultivars due to ripening progress (Al-Maaitah et al., 2009). Sterol composition was found to be influenced by cultivar for instance, the highest content of campesterol, cholesterol, β-sitosterol, and the total sterol was detected in Picholine cultivar (Giuffrè and Louadj, 2013). Olive fruit weight varies according to the cultivar (Al-Maaitah et al., 2009). They mentioned that Abo-shoka cultivar showed higher olive weight compared with the Improved Nabali cultivar. For instance, Abo-shoka cultivar performed two times higher olive weight compared with the Improved Nabali cultivar. Cultivar also exerts influences on the triglyceride composition (Giuffrè, 2013a), wax ester content (Giuffrè, 2013b), volatile compounds (Tura et al., 2013), fatty acid composition (Caporaso, 2016) and the fatty alcohol content (Giuffrè, 2014a, 2014b). Variety selection is one important factor, which should be considered prior to olive tree planting for increased harvesting efficiency (Ravetti, 2008). Giuffrè and Louadj (2013) also reported that sterols variation in olive cultivar depends. They mentioned that β-sitosterol content was high in Picholine cultivar and Δ^5-avenasterol content was high in Nociara cultivar. Olive fruits grown in the same geographic area from different cultivars produced oils with a different sterol composition (Giuffrè and Louadj, 2013).

Karagoz et al. (2017) studied Turkish olive oils (Ayvalik, Memecik, and Topakasi cultivars) and found that cultivar influences C_6 and C_5 volatile compounds which are the most important volatiles in olive oil. These parameters are very important, especially for the sensorial evaluation, in fact C_6 in an olive oil influences the fresh and green attributes (Dhifi et al., 2005). The cultivar effect was found to influence also in the phenolic composition of two cultivars (Ottobratica and Roggianella) grown in the same geographical area and studied in different ripening stages. In details, tyrosol was quantified in 16.65 - 29.39 mg/kg in Ottobratica cultivar whereas 3.78-10.67 mg/kg were quantified in Roggianella. Ottobratica presented the highest quantity of pinoresinol (57.13-88.18 mg/kg), vanillic acid (9.91-15.05 mg/kg) and *p*-coumaric acid (13.79-34.88 mg kg). In contrast, the Roggianella cultivar presented the lowest quantity of pinoresinol (21.93-52.53 mg/kg), vanillic acid (2.91-7.62 mg/kg) and *p*-coumaric acid (1.03-7.82 mg (Sicari et al., 2009; Giuffrè et al., 2010).

Growing Area/Altitude

The chlorophyll content and the carotenoids are influenced by altitude (Rouas et al., 2016). In their research, they mentioned that chlorophyll and carotenoids content gradually increase when tree age increase and it reached at peak in the 30-50 year old olive tree. In more than 50 years old olive tree, the chlorophyll and carotenoids content decrease. They analyzed the geographical condition (<300m, 300-600m, 600-900m altitude) of the Picholine Marocaine cultivar and found the 600-900m altitude growing olive contained high oleic acid which is nutritionally preferable. Olive fruit weight has varied according to the growing area. For example, Wadi-bin Hamad area showed the highest olive fruit weight compared with the Al-Mshaqar area of all cultivars (Al-Maaitah et al., 2009). The flavor of olive oils depends on its area of geographical origin because they influenced by the environmental condition (Tura et al., 2013). The growing area has impacted on the cis-3-hexenal, cis-3-hexenol, hexanal, hexanol, trans-2-hexenal, trans-3-hexenol and trans-2-hexenol (Vichi et al., 2003). The geographical cultivation area was found to influence also the fatty acid composition. In a study where South Italian and Algerian olive oils were compared, it was found that oleic acid is higher in the former instead of in the latter, besides, linoleic acid is higher in Algerian olive oil than in the South Italian ones (Louadj and Giuffrè, 2010). The fatty acid methyl esters composition is very important. Oleic acid has a positive effect on the decrease of low-density lipoprotein in human plasma and an increase serum high-density lipoprotein (Huang and Sumpio, 2008). Linoleic acid (C18:2n-6) studied in animal models which have shown a positive effect on colorectal, prostate and breast cancers (Escrich et al., 2007), even if it has two double bonds and it is more susceptible to oxidation.

Environmental Condition/Growing condition

Olive is a xerophyte plant that needs 22 to 32 °C (Caporaso, 2016). Environments have effect on enzymes and the chemical composition of olive oil (Romero et al., 2016). They described that cultivars need to adjust in growing conditions. Cooler environments produce higher oleic acid levels than hot environments due to fewer chemical reactions and less microbial activity (Rouas et al., 2016). The growing season persuades the wax esters in olive oil, and pomace olive oil contains higher wax esters (Giuffrè, 2013b). Olive flowering requires spring temperatures, growth and development need high temperatures and olive fruit ripening needs heavy rain (Tupper, 2012). Temperatures have an effect on the diseases and insects. In summer, for instance, mild temperatures increase fly infestations, and hot temperatures reduce fly infestations in olive tree (Wang et al., 2009). Hot seasons and environments, increase palmitic and/or linoleic acids and decrease oleic acid content (Lombardo et al., 2008). The olive fruit growing season influences the campesterol, stigmasterol, β-sitosterol, and Δ^5-avenasterol levels in olive oil (Giuffrè and Louadj, 2013). They also mentioned that sterol variation in olive fruits happens due to gene and/or environment. Konuskan and Mungan (2016) studied two Turkish cultivars (Gemlik and Halhalı) in two different growing conditions in Turkey and found that β-sitosterol, erythrodiol, uvaol and total sterolic content were significantly different. Mansour et al (2015) studied Chemlali and Neb Jmel cultivars in two geographical areas, both at the Center and in the South of Tunisia. Olive trees (40 year-old) were not fertilized, in rain-fed condition, without pesticide application and growing in sandy loam to loamy sand soil. Their findings were that both cultivars in both the geographical areas presented significant differences in free acidity, peroxide value, K232, K270, carotenoids, chlorophylls, oil stability index, total phenols, fatty acids, squalene and volatiles.

Soil/Pedology

Studies were conducted on the effect of soil on olive and olive oil quality. Pedologic (sandy, clay, stony, limestone, gypsum and brown soil) conditions influencing the α-tocopherol, the sterols composition and the volatiles of the olive oils (Rached et al., 2017a). They mentioned that the stony soil contained the highest α-tocopherol, limestone soil contained the highest campesterol, clay soil contained the highest stigmasterol, and sandy soil contained the highest β-sistosterol of 'Chemlali' cultivar. A significant low oil stability index was found in olive oil produced from soil, limestone and gypsum (3.34 h) if compared with oil from soil brown (18.01 h). In the same work, 61.05% oleic acid and 15.80% linoleic acid content was found in clay soil, and 47.16% oleic acid and 25.64% linoleic acid was found in limestone soil and gypsum growing olive oil (Rached et al., 2017b).

In limestone rich soil, for instance, the chlorophyll contents and the polyphenols decrease (Rouas et al., 2016). Peroxide value is affected by the soil type. For instance, Rached et al. (2017a) reported that clay soil grown olives showed the lowest peroxide value in the oil, and sandy soil growing olives showed the highest peroxide value in the oil. In a study conducted in Turkey on Kilis Yaglik cultivar fatty acid composition of olive oil from drupes harvested in mid-December, and found that palmitic acid was positively correlated with $CaCO_3$ (0.68) and with K in the K_2O form (0.58) (Cetinkaya and Kulak, 2016). They were also found that stearic acid was negatively correlated with $CaCO_3$ (-0.85) and positively correlated with total salt percentage (0.58), P as P_2O_5 (0.71) and K in the K_2O form (0.58). One of the problems existing in the Mediterranean olive grove soils is lower organic matter content (Trigo et al., 2009). The use of wastes from olive processing showed positive effects on soil, in fact leaves addiction was found to reduce by 89.2% soil loss; pomace addiction reduced erosion by 65.4% and waste water improved texture, increased nitrogen and organic matter content (Parras-Alcántara et al., 2016), with positive effects of olive and olive oil quality, production cost reduction, and environmental benefits in olive and olive oil production.

Tree age

Total phenol content is influenced by the age of the tree, and 30-50 years-old olive trees showed the highest phenol content compared with 10-30 years-old trees (Rouas et al., 2016). They mentioned that the 30-50 years-old olive trees showed the highest polyphenols content and the 10-30 years-old trees showed the lowest polyphenols content in the Picholine Marocaine cultivar. Oleic acid content depends on tree age, temperature and rainfall, which have an impact on the oil biosynthesis (Beltran et al., 2004). They described that agronomical factors are different for each fatty acid. Chtourou et al. (2017) reported that α-tocopherol, saturated fatty acids, squalene, total tocopherols, decarboxymethyl oleuropein aglycon, hexanal, 1-penten-3-ol, (Z)-2-penten-1-ol and (Z)-3-hexenal have significant documented differences in the amount detected depending upon tree age.

Treatments

The phenols and *o*-diphenol contents of the oils decrease for the sake of fertilization treatments (Romero et al., 2016). Boron alters the biochemical functions of phenylalanine ammonia lyase, peroxidase and polyphenol oxidase activities (Golbach, 1997). Boron deficiency increases phenol content (Camacho-Cristobal et al., 2002), but boron with zinc treatment in the semi-arid area increase the quality of olive fruit phenolic compounds (Saadati et al., 2013). The *o*-diphenol contents and antioxidants decrease due to protein synthesis of the high concentration of nitrogen (Jones and Hartley, 1999; Romero et al., 2016). High availability of nitrogen and potassium catalyzes the oxidation of *o*-diphenols to produce quinines (Tekaya et al., 2013). Salinity increases phenolic compounds (tyrosol, hydroxytyrosol and vanillic acid) and fatty acids (Ahmed et al., 2009).

Irrigation of olive trees

There is no effect of irrigation on olive oil production (Ramos and Santos, 2010). However, olive oil derived from the fruit of a plant that received no irrigation might have a bitter taste (Servili et al., 2007). Water stress reduces the olive production by reducing the endogenous esterases of fruit, but more water availability decreases volatile compounds (trans-2-hexenal, cis-3-hexen-1-ol and hexanol) in the fruit (Caporaso, 2016). Due to insufficient rainfall, irrigation is needed by olive tree orchards because it helps to increase olive fruit yield as well as its oil quality (Ramos and Santos, 2010). Findings of four harvest years, evidenced that yields are not significantly influenced if irrigation is stopped from fruit set (20 days after full bloom) until a Ψ stem threshold level of -3.5 MPa, whereas olive oil content and its composition were significantly influenced if Ψ stem thresholds of -5.0 (T3) and -6.0 (T4) MPa (Ahumada-Orellana et al., 2017). Studies on Moroccan Picholine cultivar demonstrated that olive trees in which 100% of the evapotranspirated water was furnished to the two sides of the root zone system of plants had a significantly lower production instead of plants in which water was furnished only in a section of the root zone system (Aganchich et al., 2008). In super-high density orchards the Koroneiki cultivar free acidity may be lowered by a moderate water stress, but if water stress is increased, the polyphenol content and the monounsaturated fatty acid/polyunsaturated fatty acid ratio are negatively influenced (Dag et al., 2015). Moreover, in Arbequina cultivar oil content increases if the irrigation is below the 30-40% of crop irrigation requirement, afterwards both olive oil and polyphenol content decrease (Marra et al., 2016).

Fruit ripening

During ripening, linoleic acid increases due to oleate desaturase that change oleic acid to linoleic acid in the olive (Gutierrez et al., 1999). The peroxide value increases in olive ripening because of the enzyme lipoxygenase activity (Rotondi and Lercker, 1999). The olive's chlorophyll content decreases and anthocyanins, carotene and carotenoids content increase during fruit ripening (Al-Maaitah et al., 2009). The olive fruit loses water during ripening due to epidermal opening or cracks of protective wax in the epicarp of lenticels or drupes metabolism process (Cimato, 1990; Tombesi et al., 1994). During the olive fruit ripening process, oleic and linoleic acids increase and palmitic acid decreases because of the different enzymatic activities (Beltran et al., 2004). The olive fruit maturation degrees play a crucial role in the chemical and sensory elements (Gómez-Rico et al., 2009). The ripeness influences the volatile compound concentrations (Tura et al., 2013). They mentioned that the early mature stage olive fruits showed higher volatile compound concentrations compared with late mature stage olive fruits. Fatty acid concentration is affected by the ripening of the olive fruit, and its concentration varies depending upon the variety (Caporaso, 2016). It happens because of the biosynthesis variation of the ripening in different varieties. Over-ripening the olive fruit showed higher oil content and its acidity compared with early ripening olive fruit in both cultivar Frantoio and Manzanilla which cultivated in Western Australia (Alowaiesh et al., 2016).

Harvest Time/Date

The olive harvesting date has an impact on the oil acidity and the peroxide value (Al-Maaitah et al., 2009). They reported that the peroxide value gradually increases from October to December in both growing areas of three cultivars. In addition, this harvesting date influences the fatty acid (oleic acid), saturated acids (palmitic and stearic) and polyunsaturated acids (linoleic and linolenic) composition of olive oil (Beltran et al., 2004). The alcohol content in olive oil is influenced by the harvest time (Giuffrè, 2014b). He also mentioned that tetracosanol showed a highly significant at harvest date. Olive fruit moisture delays the harvesting time, and late harvesting time increases the olive oil content (Alowaiesh et al., 2016). The harvesting time normally depends on environmental condition(s), which affect the olive oil composition of the fruit (Giuffrè, 2014c). The optimum ripening period should consider the olive ripening, fruit attachment force or fruit removal force, oil content in the fruit, moisture content in the fruit, oil quality evolution, natural fruit drop, impact of harvesting time for next year's crop and cheap harvesting (Ravetti, 2008).

Olive harvesting period

Olives can be harvested at different times or stages of maturation, thus obtaining different products.

Herbaceous stage: It is generally reached during the month of October, although for some very late cultivars it can reach the beginning of December. At this stage the olives are rich in chlorophyll and the oil obtained will contain many antioxidant substances. The taste of the oil will be particularly fruity and with that touch of pleasant spiciness.

Full ripening and maturation: At this stage the olives are ripe at the right point, have purple peel and oils with a sweet taste can be obtained. The 'danger' of this phase is that ripe olives, if fallen on the ground, can be affected by bacteria, mold or mud.

Over ripening: In this stage, the oil obtained from an overly ripens olive that has a less intense flavor and a lower or higher quality.

Maturity has effect of the phenolic and volatile compounds of olive fruit (Gómez-Rico et al., 2006; Caporaso, 2016). They found maximum volatile aroma concentration in the first color starting stage and afterwards aroma concentration decreased. As the olive fruit matures, the peroxide value increases (Al-Maaitah et al., 2009). Less mature olive fruits contained less peroxide value and high mature olive fruits contained high peroxide value. The trans-2-hexenal concentration decreases as the maturity of the olive fruit progresses (Toker et al., 2016). At full maturity stage, olives increase negative sensory attributes (Caporaso, 2016). He also mentioned that over ripened olive fruits obtained bitter, pungent sensory due to 1-penten-3-ol concentration. Immature olives contain higher phenolic compounds compared with ripening fruit (Ayton et al., 2012). Delayed ripening increases the olive oil free fatty acid to help of lypolytic enzyme activity (Anastasopoulos et al., 2011). Wax ester content in olive oil was found to vary during fruit ripening (Giuffrè, 2014c), this is mainly due to the biosynthesis of very long chained fatty alcohols (Kunst and Samuels, 2009) and to a mechanism of defense of fruit from environmental factors such as the high temperature which increases the wax production.

Fruit Picking/Harvesting Systems

Olive harvesting is a very important phase for the production of extra virgin olive oil because the used techniques affect the taste of the oil, its quality and the reference market in which it is commercialized. Based on the use of certain olive harvesting methods, the final product takes on different aspects and organoleptic characteristics, which are also reflected in the final cost and quality level of olive fruits and olive oil. Many harvesting methods exist and many variables are applied. The choice of a method instead of another one depends on many factors such as: age of the plants, shape/profile of the ground, the size of the olive tree orchard, shape and size of the canopy, concurrent or gradual fruit ripening, cost of the workmanship, cost of machineries (Ferguson, 2006; Ferguson et al., 2010; Gambella, 2013; Gertsis et al., 2013; Deboli et al., 2014; Famiani et al., 2014; Almeida et al., 2015; Jimenez-Jimenez et al., 2015). Here we describe the main techniques used for this purpose.

Fruit natural drop

This technique is an indicator of an obsolete agriculture. It consists in picking the olives once ripe and then when they spontaneously and without an external stimulus fall from the branches of the olive trees on plastic nets placed under each canopy. This procedure continues for 15-25 days from the start of the fruits falling until the large part of the fruits is fallen. For sure the oil obtained from these olives will have some defects due to molds, pests, and oxidation or lipase actions.

Hand picking

This is the slowest and most expensive method but it is also the best one because it allows the producer to get the best quality of the fruit and also do not damage the plants. The harvester uses a ladder to step up to the tree foliage.

Drupes are the handpicked and placed in baskets. This system is the only one possible if the olive is consumed fresh because they do not have to show dents or lesions that would depreciate them. Fruits must also be clean and intact and not dirty with earth or molded. The highest-quality oils are produced with this technique. The process is slow, accurate, allows picking the olives by hand and selecting them from time to time.

Hand held combs and hand held mechanical combs

Hand held combs consists in passing between the branches a large wooden or plastic rake installed on a telescopic pole that 'comb' and detaches the fruits which are collected in a cloth that is placed under the olive tree or in a net that is placed under each plant. When the ground surface is in the plain, it can be used a container that looks like an upside-down umbrella that surrounds the trunk of the tree. When the ground is sloping a plastic and flexible net is placed under the tree and fruits are immediately collected. Unfortunately, this method causes damage to the young branches and it can cause detach of many leaves. Recently, mechanical combs have been proposed which allow good yields and reduce working time. The branches of the trees are vibrated through a special tool (vibrating tools) that allows the drupes to fall and be harvested.

Branch beating

It is a very ancient method that consists in beating the branches of the trees with long poles to drop the drupes. The fruits fall down in a plastic net placed under the tree canopy and are immediately transferred in plastic containers before to be carried to the industrial plant for oil extraction. If fruits are in a good phyto-sanitary condition, a low free acidity is expected. The contraindication is that beating the branches could break them or injure them; especially the young twigs that will bring the fructification of the following year and the olives are also bruised. In brief the falling of fruits can change their consistency and moreover the tree structure can be damaged.

Branch shaking

Branch shaking is conducted by a pneumatic and vibrating arm, causing the olives falling in large nets arranged on the surface of the ground, under the canopy of the tree and which are quickly collected. This is a variety of branches beating with the advantage to reduce damages to branches, twigs and fruits. Branch shaking can be conducted on trees 2.5-3.5 m high.

Trunk shaking

It is often associated with the previous technique. The tree shaking with special machines allows collecting the olives once ripe. It is carried out by means of a mechanical arm installed on a medium-powered tractor that shakes both the tree and its branches. The positive aspects are that olives are collected in a net placed under the olive tree and are healthy and not dented and the quality of oil is safeguarded. If the tree shaking is correctly performed and if drupes are ripe, the percentage of detachment of the drupes from the tree is more than 85%. In addition, this harvesting method is fast and there is no need for much manpower. The contraindication for mechanical olive picking by the trunk shaking are the high initial cost of the machine which can operate only where the olive tree plantations are in plain. If the olive orchards are on small surfaces, it is expensive use this picking method. If plants are too high (Sinopolese cultiver grown in Calabria Region, Southern Italy, is 10-15 m high) it is necessary to apply more force and the risk is of roots damaging. A moderate force has to be applied also to older plants. This type of harvest to be profitable needs plants that are single stems placed regularly on the lines and between the lines to facilitate the mechanical operations, besides fruits have to ripe at the same time.

Straddle harvesting

Many types of straddle harvesters exist. Some of them were adapted from other industries such as the grape harvester with beaters or with rotating heads. In general, a straddle harvester is composed by a tunnel which passes over the tree and shakes the branches, this movement consents the fruits to fall down in a food-quality container. This harvesting system can be applied for a super intensive orchard and it is related to the orography of the territory (in plain), the cultivar (with a central axis slightly taller than 2 m, which can however reach up to 4 m of height, with the final 1.5 m portion flexible enough to avoid damage by the harvester and lateral branches oriented in parallel with the row) (Giametta and Bernardi, 2010). The grove design is very important because the harvester has been able to move on the row and between the rows, in addition it has to turn at the end of the row. Straddle harvesting consents to reduce the production cost which is one of the most concrete problems in the olive and olive oil industry (Bernardi et al., 2018).

POST-HARVEST FACTORS

Fruit storage, leaf removal and fruit washing, fruit crushing, paste malaxation, oil extraction systems, oil storage and cooking are discussed in this section.

Fruit storage

Between harvesting and processing olive fruits have to be stored no more than one day because longer storage time may hydrolyze the triglycerides to free fatty acids with the action of lipases, in the presence of moisture. For this reason it is advisable to process olive fruits as soon as possible, for instance within 4-5 hours of harvest. The harvest season is short, by and large from mid-October to the end of December; therefore, in the geographical areas where the olive cultivation is massive, sometimes it is difficult or impossible to process all fruits when they are at the right maturity stage. As a consequence it could be useful storing fruits in an appropriate way to oil extraction. Asheri et al (2017) stored at – 4 °C, for one and three weeks, fruits of Mission, Arbequina and Koroneiki cultivars grown in Iran. They found that peroxide and chlorophyll values were higher in oil from fruits processed immediately after harvesting than in oil from fruits frozen for one or two weeks. The oil content was significantly higher in Mission cultivar used as a control than in Mission cultivar frozen for one and three weeks. No statistical differences were found in Koroneiki oil content and a partially significant difference was found in the Arbequina oil content. Flores et al (2006) treated olive fruits with methyl jasmonate in ethanol and found a decrease in the total saturated fatty acid content, both after 15 and 30 days storage, whereas an increase in oleic, linoleic and linolenic acid was detected. In the same study, gallic, chlorogenic, vanillic, caffeic, *p*-coumaric and caffeic acids were significantly higher in the pulp of methyl jasmonate treated fruits for both 15 and 30 days than in the control sample at 0, 15 and 30 days. Poerio et al. (2008) studied the fruits of Colombaia cultivar grown in Liguria Region (Italy) and found that freezing influenced positively both the free acidity and the peroxide value which were significantly lower in oil from frozen olives than in oil from the control and unfrozen. In addition, they also found an inverse effect in the oil stability index whose value was higher in the oil from control olives (22.48 h) than in oil from olives processed directly as frozen (20.16 h) or in olives processed after thawing (15.73 h). Morales-Sillero et al. (2017) studied the fruits of Manzanilla de Sevilla and Manzanilla de Cacereña cultivars grown in Portugal for 11 days from harvest. They found that fruit, storing at 2 °C delayed the fruit decay in Manzanilla de Cacereña whereas olive refrigeration had no effect on fruits of Manzanilla de Sevilla cultivar that was mechanically harvested. This difference could be due to the damages on fruits caused by mechanical 'straddle' harvester and the consequential beginning of decay at harvest. Hbaieb et al (2016) studied the effect of storage on the olive oil volatiles profile in Chétoui and Arbequina cultivars grown in Tunisia.They found an increase in C_6 aldehydes when fruits were stored at 25 °C and a decrease when fruits were stored at 4 °C, this phenomenon was more evident in oils from Arbequina cultivar. The hexanal showed an inverse trend and showed a slight decrease when fruits were stored at 4 °C and an increase when fruits were stored at 25 °C. These aspects are very important because these compounds are responsible for the flavor of olive oil and for its sensory quality (Kalua et al., 2007).

Leaves removal and fruit washing

Leaf discards are needed for harvested olive fruit. The green leaves increase in the green color of olive oil and organoleptic sensation (color, aroma and taste) of green color may not preferably to consumers (Di Giovacchino et al., 2002). In contrast, green color oils to prefer by a consumer for the reason that its freshness (Ayton et al., 2012). If higher percentage of green leaves present during crushing than chlorophyll pigment (green color) and the *trans*-2-hexenal content increase (Di Giovacchino et al., 2002). Chlorophyll converts to pheophytin and pyropheophytins due to heating or aging (Ayton et al., 2012). Both *cis*-3-hexenal and *trans*-2-hexenal is liable for the green aroma of oil (Olias et al., 1993). On the basis of variety and maturity stage, virgin olive oil showed green-yellow to golden color range (Salvador et al., 2001). Olive washing ensures safety and hygienic that helps to maintain the natural quality of oil (Di Giovacchino et al., 2002). Free fatty acid percentage increases if leaves are not removed and/or the olive fruit is not washed (Gharbi et al., 2015).

Fruit crushing

There are two types of olive crushing systems: with a granite stone mill (old-traditional system) and with metallic crushers (modern systems). Plants with stone mill and hydraulic presses are no more produced, and only a very few number of traditional machinery is actually in use. The modern systems are equipped with disks or hammers or knives metallic crusher. The crushing methods influence the sensory element of olive oil (Gómez-Rico et al., 2009). Prolonged crushing time may degrade the quality of the olive oil. The recommended olive crushing time is 20-30 minutes because crushing the fruit within this time window produces less peroxide (Gharbi et al., 2015). The milling system has an impact on the oil quality as well as the organoleptic properties (Caporaso, 2016). Findings on Arbosana cultivar grown in California showed that the hammer mill rotor speed do not influence free acidity, peroxide value, spectrophotometric indices, whereas oil content, bitterness, pungency, chlorophylls, 3,4-DHPEA-EDA, *p*-HPEA-EDA, and total phenols, increases with hammer mill rotor speed from 2400 to 3600 rpm (Polari et al., 2018).

Paste malaxation

The conditions applied during malaxation, such as temperature, composition of the atmosphere which is in contact with the olive paste, time (duration), can influence the enzyme activity which is responsible for the sensorial properties and the health of the product (Clodoveo, 2012).

Olive paste mixing facilitates formation of tiny oil droplets to make bigger ones, which can be removed during the next step. Temperature and olive paste mixing time is important to control the oil quality. Malaxation reduces to emulsion form of metallic crusher and its efficacy depends on paste texture, mixing time (10-20 min) and temperature (20-25 °C) (Di Giovacchino et al., 2002). Temperature influences the peroxidase, polyphenol oxidase, and lipoxygenase oxidative enzymes, which are responsible for the quality of volatile compounds of olive oil (Angerosa, 2002). Researchers should follow the rotation, speed 15-20 rpm and have to avoid addition of water in lieu of adjuvants during malaxation of paste (Gharbi et al., 2015). Shorter malaxation is better than longer one. Longer malaxation promotes the alcohols and hexanal in olive oil (Caporaso, 2016). Malaxation process alters the olive oil aroma if the concentration of oxygen and phenolic compounds decreases due to the enzymatic oxidation of the polyphenol oxidase and peroxidase (Servili et al., 2008).

Jolayemi et al. (2016) evidenced the influence of malaxation temperature on the chemical properties of olive oils. They compared oils obtained after malaxation at 27, 37 and 47 °C from Ayvalik and Memecik cultivars grown in Turkey and found that the effect of malaxation is related to the ripening stage of the olives. The lowest free acidity percentage was found at 37 °C in both cultivars and at all the ripening stages, whereas total phenolic content showed a tendency decrease in early and late harvested olives and an increasing content in mid (3.23-3.57 ripen an index) harvested fruits.

Oil extraction systems

By using pressure, centrifugation and percolation; olive oil is extracted in olive oil mills from the paste (Di Giovacchino et al., 2002). The oily-must (olive oil + water) can be separated from the solid phase (pomace) with the help of mats and stone fragments (Di Giovacchino et al., 2002). Improper oil extraction systems may influence the oil off-flavours. Co-adjuvants (mineral talc and enzymes) help to increase the free oil quantity of olive paste (Di Giovacchino et al., 2002). In the traditional (old) systems, after the pressure of the olive paste, the separation of oil from water was done by natural decanting (settling) or by centrifugation. Natural decanting was a slow process and required more time, more labor and oil may end up contaminated, whereas centrifugation fast process, needs less time, less labor and less impure oil at the end of the process (Di Giovacchino et al., 2002).

Nowadays the modern (continuous) machineries mainly involved the so called three or two phase extractors.

Three phases. The olive paste, suitably prepared by malaxation, is put into the centrifugal extractor via a single screw pump with a variable flow. The extractor separates the two liquid phases (oil and waste water) in two outputs and the third solid phase on the opposite side. When the olive paste is introduced in the horizontal centrifuge, warm water (max 27 °C) is also added to facilitate oil extraction. The contraindications of this system are large volumes of waste water to discharge and a loss of phenols in the waste water.

Two phases. The centrifugal extractor has only two outputs, one liquid for oil and one for pomace and water. This type of extraction reduces or eliminates the use of water process, with the double advantage of limiting the use of natural resources (water) and to reduce or eliminate the production of waste water, whose disposal has a significant impact on the management costs of the oil mill. The contraindication of this system is that the discharged pomace is very wet, and the pomace oil extraction with a non-polar solvent (*n*-hexane) is very expensive.

Two phases and half. This is the most recent type of decanter and summarizes the advantages of the three and two phase systems. The processing requires the addition of a reduced amount of water and separates three fractions (oil must, waste water and wet pomace). The advantage of this system is that a lower quantity of waste water is produced and with a lower polluting charge because a lower quantity of phenols is dissolved in the waste water. The wet pomace still has a low value because the pomace oil extraction is expensive (more than in the pomace obtained by a three phase system), but it can be treated with systems that allow an economic recovery by exploiting the energy potential of the pits which can be used as a fuel in burners or in pellet stoves.

Klen and Vodopivec (2012) studied the effect of traditional (by pressing) and two and three phase extraction systems (by centrifugation) on the phenolic fraction. The three phase systems extracted oil containing the highest oluropein, tyrosol, hydroxytyrosol and rutin content.

Kalogeropoulos et al. (2014) studied the Koroneiki cultivar in Greece and found significant differences in oils obtained from two or three phase technologies. The two phases produced oil with a higher hexanal and nominal content together with more total phenols and a lower peroxide value whereas. No significant differences were found in terms of free acidity and spectrophotometric indices (K232 and K270). Similar findings were obtained by Ammar et al (2014) in oil from Chemlali cultivar grown in Tunisia. They also found a lower total wax content, a higher total flavonol content and a higher α-tocopherol content in oil processed with a two phase decanter.

Oil Storage

Olive oil deterioration happens in plastic containers due to interactions between oxygen and the unsaturated fatty acids during storage (Gargouri et al., 2015). In addition, light is a substantial factor contributing to deterioration in the quality of olive oil. UV light absorbed by fatty acids, which help to determine the quality of olive oil (Ayton et al., 2012). During storage, acidity and peroxide values increase and chlorophylls, carotenes and phenols decrease (Gargouri et al., 2015). The optimal storage condition for olive oil was found to exist in tin containers and dark glass bottles for 180 days at 20 °C (Gargouri et al., 2015). The method of oil filtration, exposure to light, oxygen, temperatures and the trace elements which promote the lipid oxidation also shorten the shelf life and sensory properties of olive oil (Caporaso, 2016). Not only is olive oil sensitive to storage a condition, the quality of other vegetable oils is also influenced by storage duration and environment (Caporaso, 2016; Mele et al., 2017). Phenolic compounds have an antioxidant ability which prolongs the olive oil shelf life stability (Mailer et al., 2005). Induction times increase the stability and shelf life of olive oil (Mailer et al., 2005; Ayton et al., 2012). The α-tocopherol reduces over time of storage regardless of the control storage temperature, but low temperatures (15-22 °C) decrease the degradation rate of α-tocopherol. High temperatures (over 37 °C) hasten the degradation rate of α-tocopherol and increase the rancidity to the point that the oil becomes virtually inedible unless refined (Ayton et al., 2012).

Cooking

Olive oil can be used for boiling, curry-making, frying (deep and pan), microwave cooking and roasting. The oil quality normally degrades due to oxidation, hydrolysis and polymerization with the passage of long time and high temperature cooking (Santos et al., 2013). Although olive oil has thermal oxidation resistance ability, it may lose bioactive attributes during cooking (Santos et al., 2013). The cooking temperature, the cooking duration and their combination are variables significantly affecting the degradation rate of some olive oil's physicochemical parameter, such as peroxide value, spectrophotometric indices, antioxidant activity, phenolic content, *p*-anisidine value, totox, iodine value, oil stability index and density, whereas free acidity is not significantly influenced by these variables (Giuffrè et al., 2017).

CONCLUSION

From the above discussion, we can surmise that many factors (pre- and post-harvest) are involved in the quality of olive fruit and its oil compositions. In brief, the cultivar, growing area, environmental condition, soil, tree age, treatment, irrigation, fruit ripening, harvest time, maturity and fruit picking are pre-harvest factors. In addition, the post-harvest factors such as fruit storage, leaf removal and fruit washing, fruit crushing, paste malaxation, oil extraction systems, oil storage and cooking should be considered. Therefore, the quality of olive fruit and its oil compositions can be possible to maintain by the above pre-harvest and post-harvest factors.

Author contributions

All authors are equally contributed to write and revise the manuscript.

AKNOLEDGEMENTS

This research was supported by: Distretto ad alta tecnologia agroindustriale della Calabria AGRIFOODTECH – PROGETTO PON03PE_00090_2. Sustainable models and new technologies for olives and olive oil.

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