# Influence of olive processing on virgin olive oil quality

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Virgin olive oil quality depends on different factors such as olive cultivar, olive tree cultivation and the operations of olive picking, storage and processing. Many investigations concerning these factors were carried out and, in particular, the influence of technological operations of olive processing on oil yields and quality was examined. Leaf-removal and olive washing are important operations for the mechanical safety of the olive extracting equipment which operates at high speed and for the organoleptic quality of olive oil. The leaves mixed with olives may increase, in fact, the organoleptic attributes of 'fresh-cut' grass or 'green', especially if metallic crushers are used to prepare olive paste. Olive crushing has an important influence on organoleptic and nutritional qualities of virgin olive oil. When mill stones are used, the obtained oils have a lower intensity of bitterness and pungency because this crushing method helps to produce oil with a lower content of phenolic substances. When metallic crushers are used oils have, due to the violent action, a higher content of phenolic compounds and are more bitter and pungent. Olive paste malaxation influences the oil yields and also the antioxidant content of oil. With prolonged malaxation oil yields, generally, increase while the phenol content of oils decreases. When 'difficult' olive pastes are processed, it is possible to increase oil yields by using technological co-adjuvants such as talc and enzymatic products during the malaxation. The separation of oil from solid and liquid phases of olive paste is performed by using either pressure, percolation or centrifugation systems. All systems may provide good-quality oil if olive fruits are sound and at the correct ripeness, but the centrifugation system helps to avoid or reduce the risk of an organoleptic contamination. The new centrifugal decanters, operating without adding water (or only a minimal amount of water) to olive paste, save heat energy and the oils obtained are more fruity and have a higher content of natural phenolic antioxidants.

**Keywords**: Virgin olive oil, olive processing, virgin olive oil quality.

## 1 Introduction

Virgin olive oil quality depends on many factors related to olive tree cultivation and to the harvesting, storage and olive processing steps. Of particular importance for olive oil quality are the olive cultivar, the pedoclimatic conditions of cultivation, as well as the pruning, fertilisation and irrigation of olive trees. In reality, the good quality of olives at the moment of picking is a decisive, but not the only factor ensuring a good quality of the olive oil. It is important, however, that the quality does not deteriorate during processing. Therefore irrational operations should be avoided.

In this review results obtained in investigations undertaken on technological operations of virgin olive oil extraction are reported and discussed.

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## 2 Leaf removal and washing

Generally, olives are picked from the tree by hand or by mechanical devices. In some cases, olives are picked from the ground or nets are placed under the tree crown. In any case, olives are contaminated with vegetal impurities, such as leaves or twigs, and with mineral impurities, like soil, dust and stone fragments.

Extraneous matter, even if its origin is natural, mingled with olives, must be removed to avoid negative influences on the quality of virgin olive oil and on the mechanical safety of the equipment utilised for olive oil extraction. Separation of extraneous material is carried out by a leaf-removal and washing machine.

The influence of leaves crushed with olives on virgin olive oil characteristics is an increase in green colour in the oil and the organoleptic sensation of "green" or "leaves", that may not be agreeable for consumers. However, the intensity of this sensation depends on the efficiency and vio-

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**Tab. 1.** Characteristics of virgin olive oils obtained by a three-phases centrifugal decanter from olives added with different quantity of leaves [1].

| Determinations | Cv. Dritta | | | Cvs. Leccino + Castiglionese | | |
|---|---|---|---|---|---|---|
| | Leaves [%] | | | Leaves [%] | | |
| | 0 | 3 | 5 | 0 | 3 | 5 |
| Free fatty acids [%] | 0.66 | 0.70 | 0.62 | 0.54 | 0.58 | 0.56 |
| Peroxide value [meq$O_2$/kg] | 8.1 | 8.8 | 8.4 | 4.2 | 4.9 | 5.2 |
| $K_{232}$ | 2.01 | 1.95 | 1.99 | 1.43 | 1.57 | 1.68 |
| $K_{270}$ | 0.12 | 0.13 | 0.12 | 0.07 | 0.10 | 0.12 |
| Total phenol [mg/l as gallic acid] | 84 | 91 | 103 | 103 | 102 | 106 |
| Induction time [h] | 7.2 | 6.7 | 7.0 | 8.0 | 8.7 | 8.2 |
| Chlorophyll pigments [mg/kg] | 3.7 | 6.8 | 8.7 | 3.4 | 8.4 | 12.1 |
| Organoleptic assessment (score) | 6.0 | 6.9 | 6.5 | 6.3 | 7.2 | 6.8 |
| Green fruitiness (score) | – | 1.2 | 1.2 | – | 1.6 | 1.6 |
| Bitter taste (score) | – | 0.5 | 0.5 | – | 0.8 | 0.8 |
| *trans*-2-Hexenal [mg/kg] | 77.8 | 130.7 | 171.1 | 130.5 | 288.0 | 287.1 |
| Hexanal [mg/kg] | 16.7 | 14.9 | 26.9 | 23.2 | 26.9 | 34.4 |
| *cis*-3-Hexen-1-ol [mg/kg] | 4.3 | 19.3 | 17.0 | 2.2 | 3.6 | 5.8 |
| *trans*-2-Hexen-1-ol [mg/kg] | 17.4 | 41.0 | 49.9 | 9.5 | 14.1 | 18.9 |

lence of the olive crushing method and the comminution of leaves.

The granite stone mill, normally adopted in the olive oil mills equipped with a pressure system, has a non-destructive action and breaks the leaves only into a few large fragments. In that case, the organoleptic characteristics, colour, aroma and taste, of the resulting virgin olive oil are not influenced because the crushing method provokes a partial presence of compounds in the olive paste which are responsible for the green colour and "green grass" or "green leaf" sensation.

The metallic crushers, generally utilised in the olive oil mills equipped with centrifugal decanters, have a violent action and reduce the leaves in many small fragments releasing a large quantity of those compounds which influence some organoleptic characteristics, such as colour, aroma and taste of virgin olive oil.

Tab. 1 shows the analytical data of oils extracted with a three-phases centrifugal decanter from olive paste. The latter was obtained by crushing olives to which different percentages of leaves had been added with a fixed-hammer metallic crusher [1]. The data show that both the chlorophyll pigment (green colour) and the *trans*-2-hexenal content increase when a higher percentage of leaves was added to olives. Together with *cis*-3-hexenal and the corresponding hexenols *trans*-2-hexenal is responsible for the fresh-cut grass aroma of oil [2]. This organoleptic sensation was perceived with higher intensity by tasters when the oils were obtained from olives to which a higher percentage of leaves had been added.

Moreover, the data in Tab. 1 show that the total phenol content (mg/l) and the induction time (hours, obtained by Rancimat apparatus) of oils did practically not change when different percentages of leaves were added to olives. This is due to the fact that the concentration of the phenolic compounds (glycosides) of leaves is similar to that in olive flesh.

Olive washing is generally carried out by recycling potable water in the same machine utilised for leaf-removal. The washing operation helps to remove dust, soil, sand, stone fragments and any mineral or metallic contaminants. The siliceous materials are abrasive for the metallic parts of a crusher or decanter rotating at high speed. They can throw them out of balance and thus create a dangerous situation. Olive washing helps to avoid that risk and represents a hygienic operation that helps to preserve the natural and nutritional characteristics of oil.

## 3 Olive crushing

The extraction of virgin olive oil by mechanical means is possible because some technological operations help to liberate the oil droplets from the cells of olive flesh. Olive crushing, using the granite mills tones or the metallic crushers, is a procedure of major importance because it gives rise to the breakage of vegetable cells containing oil.

**Tab. 2.** Qualitative characteristics of virgin olive oils extracted with three-phases centrifugal decanters from olive paste obtained by different crushing methods [9, 10].

| Olive cultivar | Crushing method | Free acidity [%] | Peroxide value [meq$O_2$/kg] | $K_{232}$ | Organoleptic assessment (score) | Total phenols [mg/l] | Induction time [h] | Bitterness intensity (score) |
|---|---|---|---|---|---|---|---|---|
| Coratina | Stone mill | 0.40 | 6.5 | 1.18 | – | 228 | 9.2 | – |
| | Fixed-hammers metallic crusher | 0.37 | 5.4 | 1.20 | – | 411 | 11.9 | – |
| Peranzana | Stone mill | 0.23 | 11.5 | 1.87 | 7.4 | 133 | 7.8 | 1.8 |
| | Discs metallic crusher | 0.23 | 11.7 | 1.90 | 7.2 | 247 | 10.6 | 2.4 |

When an olive oil mill is equipped with a pressure system, olive crushing is generally carried out by a granite millstones (with 2-6 stones) for 20-30 min. The resulting olive paste is subsequently squeezed by a hydraulic press. In this way good oil extraction yields are obtained [3].

When an olive oil mill is equipped with a centrifugation system olive crushing is generally carried out by metallic crushers, such as mobile or fixed-hammers, toothed discs, cones or rollers. These crushers have a high working capacity and exert a violent action that breaks the cells of the olive flesh containing oil and gives a paste which, after a suitable step of malaxation, leads to good extraction yields [4].

Olive crushing can increase the temperature of the olive paste because a part of the kinetic energy of the crushers, which rotate either at a high speed (metallic crushers) or at a low speed (stone mill), is transformed into thermal energy for friction. The results reported in some papers [5-6] showed that the temperature of olive paste increased by 13-15 °C with respect to the ambient temperature, when a fixed-hammers metallic crusher was used, and by 4-5 °C, when a stone mill was used.

The different crushing methods may influence oil yields obtained with the centrifugation system. *Ranalli* reported that a higher oil yield was obtained when a stone mill was used [7]. However, the common opinion is [8] that the centrifugal decanter gives a higher oil yield when the olive paste is obtained by violent metallic crushers, *i.e.* fixed-hammers or discs.

Tab. 2 shows the analytical data obtained in experimental tests carried out to ascertain the influence of the crushing method on some qualitative characteristics of oils extracted by a three-phases centrifugal decanter [9, 10]. The data indicate that the crushing method, using stone mill (gentle) or metallic crushers (very violent), does not influence the qualitative parameters of oils, like free fatty acids percentage, peroxide value, specific spectrophotometric absorptions in the UV region and organoleptic assessment. The values of these parameters, in fact, depend on the cultivar, quality and health of the olives and not on the different crushing methods used.

The crushing method, however, has a clear influence on the total phenol content of oils (Tab. 2). The use of the more violent metallic crushers helps to obtain oil with a total phenol content higher than that ascertained in oils obtained using a stone mill. This is due to the more complete breakage of olive flesh that liberates higher quantities of phenolic substances, which are bonded to the different cellular tissues of the olive flesh, and hence increases their concentration in the olive paste.

Although different results were reported on this subject [12, 13], the data in Tab. 2 confirm that virgin olive oils obtained from the centrifugation of olive paste prepared by a metallic crusher have a higher content of total phenolic compounds and, consequently, a higher value of induction time (h) as measured by the Rancimat apparatus. Moreover, the same oils cause a higher intensity of the bitter taste, as perceived by the panel of tasters.

Previous results indicated that the use of a fixed-hammers metallic crusher equipped with a grille with smaller holes (more violent) helped to obtain oils with a higher content of total phenolic compounds [14]. That result was confirmed by other investigators who varied the relative rotational velocity of the hammers of a metallic crusher (Tab. 3) [13, 15]. These results show that oils obtained by increasing the relative rotational speed of the fixed-hammers of a crusher and, consequently, by a more violent crushing, are more bitter and have a higher content of some phenolic compounds.

The preceding evidence suggests that the use of a stone mill to crush some olive varieties that generally give oils with intense bitter and pungent characteristics, which are not necessarily agreeable to consumers. This is true for the olive cultivars of some Southern Italian regions which exhibit more frequently the above-mentioned characteristics than olive cultivars of other regions. Stone mills, however, have a low working capacity, no more than 1.0-1.5 tons/h, and for this reason operators of those mills

**Tab. 3.** Influence of the relative rotating speed of fixed hammers of metallic crushers on the content of some phenolic compounds [mg/kg] of oils [13, 15].

| Determinations | Olive cultivars and ripening degree | Relative rotating speed of hammers | |
|---|---|---|---|
| | | 2200 rpm | 2900 rpm |
| Bitter substances | Mixed | 36.3 | 61.7 |
| | Coratina | 217.7 | 337.3 |
| Aglycons | No ripe | 546 | 612 |
| | Ripe | 316 | 421 |
| Polar minor compounds | No ripe | 800 | 1040 |
| | Ripe | 780 | 860 |

aspire to increase the crushing capacity. To this end operators of olive oil mills, which are equipped with centrifugal decanters and have a high loading capacity, use a metallic crusher in addition to the stone mill which works for 8-10 min. In that case, the action of the metallic crusher, placed after the stone mill, is not violent because it works on the olive paste that has a low resistance when passing through the holes of the grille, and therefore the organoleptic characteristics of virgin olive oil are not affected.

Of course, if the working capacity of an olive oil mill is higher than 50-80 tons/d, it only needs to use the more violent metallic crusher which also has a higher loading capacity to prepare olive paste for the decanters. That is how Spanish oil mills work.

The crushing method also affects the content of the volatile compounds of the head-space of virgin olive oil. Tab. 4 [9] shows that the use of granite millstones to crush olives subsequently processed by a three-phases centrifugal decanter helps to obtain oil with a higher content of total volatile compounds and of *trans*-2-hexenal. The latter is the most important volatile component of fresh oils giving rise to the characteristic aroma of fresh-cut grass. This result, however, seems to contradict the common observations of tasters who generally perceive a more intense sensation of fresh-cut grass when the oil is obtained from olive paste prepared with the metallic crusher and then processed in a centrifugal decanter.

**Tab. 4.** Average content of some volatile compounds of the head-space of oils extracted with a three-phases centrifugal decanter from olive pastes obtained with different crushing methods [9].

| Volatile compounds [mg/kg] | Olive crushing by | |
|---|---|---|
| | Stone mill | Metallic crusher at discs |
| Hexanal | 28.0 | 27.8 |
| 1-Penten-3-ol | 10.1 | 15.5 |
| *trans*-2-Hexenal | 321 | 121 |
| *cis*-3- Hexenyl acetate | 23.0 | 26.4 |
| *trans*-2-Penten-1-ol | 7.4 | 9.7 |
| 1-Hexanol | 8.6 | 8.9 |
| *cis*-3-Hexen-1-ol | 23.7 | 18.1 |
| *trans*-2-Hexen-1-ol | 3.9 | 4.9 |
| Total volatile compounds | 554 | 380 |

## 4 Malaxation of olive paste

The olive paste obtained after olive crushing has to be malaxed to prepare it well for the following oil separation step and favour better extraction yield. The malaxation consists of a continuous slow movement of olive paste that provides an increase in the percentage of "free oil" and helps the oil droplets to merge into large drops.

*Martinez Moreno* [16] studied this phenomenon and demonstrated that more than 80% of oil drops in olive paste had a diameter greater than 30 microns after the malaxation step. The increase in oil drop size favoured the increase in "free oil". Moreover, the malaxation helped to reduce or remove the emulsion formed during the crushing operation, especially when a metallic crusher is used.

Olive paste malaxation is carried out in semicylindrical vats fitted with a horizontal shaft, with rotating arms and stainless steel blades of different shapes and sizes. These vats are equipped with a heating jacket with circulating hot water to heat olive paste.

The efficiency of malaxation depends upon the rheological characteristics of olive paste and upon the technological parameters of operation, such as time and temperature of malaxation.

When the olive oil mill is equipped with a pressure system and olive crushing is carried out by granite millstones, the malaxation of olive paste is not very important because: i)

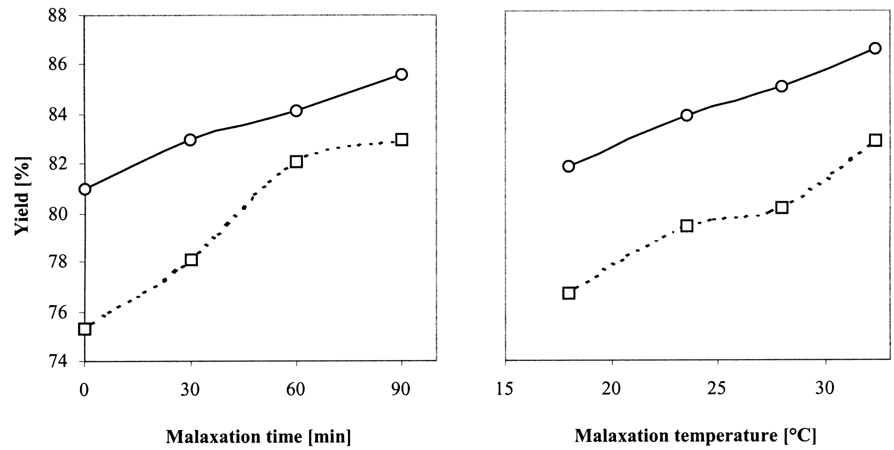


**Fig. 1.** Oil extraction yields (% of oil) contained in olive fruits, obtained with the 3-phases centrifugal decanter from "easy" (–o–) and "difficult" (- -□- -) olive pastes malaxed at different times and temperatures [20].

the slow rotation speed of the granite millstones does not cause the emulsification of oil with the other liquid and solid phases of olive paste; ii) the slow movement of olive paste during the crushing process represents a partial malaxation. For that reason, in an olive oil mill operating with a pressure system, the malaxation time for olive paste is 10-20 min and the temperature is not higher than 20-25 °C.

When an olive oil mill is equipped with either a 2- or 3-phases centrifugal decanter malaxation is very important both to break or reduce the emulsion state of oil, originated from the violent crushing operation by the metallic crusher, and to favour the formation of "free oil" in olive paste by increasing the time and temperature of malaxation.

The influence of the malaxation of olive paste on the oil extraction yield obtained with the different systems of olive processing has been studied with reference to pressure [3], percolation [17], 3-phases [18-20] and 2-phases centrifugation systems [21-23]. Generally, results indicated an increase in the oil extraction yield with increasing time and temperature of olive paste malaxation, as shown in Fig. 1 [20]. Similar results were obtained varying the malaxation time of olive paste processed with a centrifugal decanter in the water saving mode (Tab. 5) [23]. The data show that the quantity of the oil lost in the form of by-products (pomace and vegetable water) was significantly reduced when the malaxation time of olive paste was increased from 15 to 90 min.

The malaxation may influence some analytical characteristics of an oil (Tab. 6) [23]. The data show that the commercial qualitative parameters of virgin olive oil, like free fatty acids, peroxide value, specific spectrophotometric absorptions in the UV region and organoleptic assessment [23], did not change when the malaxation time of olive paste was increased from 15 to 90 min. These parameters depend on the cultivar and quality of olives before their processing. Therefore and because of the protective action of phenolic antioxidant substances in the olive paste, they cannot change during the malaxation step, even if it is extended to 90 min.

The total phenol content and induction time of oil only diminished when the malaxation time was increased. This result is in agreement with other reported investigation results all of which refer to the different olive processing systems [14, 15, 19-29].

However, it is important to point out that the total phenol content of oil obtained varying the malaxation time from 15 to 90 min diminished when the experiments were per-

**Tab. 5.** Average quantitative results obtained from the centrifugation, using a centrifugal decanter set to water saving, of olive pastes malaxed for different times [23].

| Determinations | Malaxation time† | | |
|---|---|---|---|
| | 15 min | 45 min | 90 min |
| Oil extraction yield [%] | 78.5$^{a}$ | 82.8$^{b}$ | 85.7$^{b}$ |
| Oil in the pomace [kg/100 kg olives] | 3.1$^{a}$ | 2.6$^{a}$ | 2.2$^{a}$ |
| Oil in the veg. water [kg/100 kg olives] | 0.7$^{a}$ | 0.5$^{a}$ | 0.3$^{a}$ |
| Total oil lost in by-products [kg/100 kg olives] | 3.8$^{a}$ | 3.1$^{ab}$ | 2.5$^{b}$ |

† Values with the same letter do not differ statistically.

**Tab. 6.** Average values of some qualitative parameters of oils extracted by a two-phases centrifugal decanter from olive pastes malaxed for different times and obtained from 5 different olive lots [23].

| Malaxation | | Free acidity [%] | Peroxide value [meq$O_2$/kg] | $K_{232}$ | $K_{270}$ | Organoleptic assessment (score) | Total phenols [mg/l] | Induction time [h] |
|---|---|---|---|---|---|---|---|---|
| Time [min] | Temperature [°C] | | | | | | | |
| 15 | 24 | 0.37 | 4.5 | 1.49 | 0.10 | 6.9 | 293 | 14.3 |
| 45 | 24 | 0.36 | 4.8 | 1.49 | 0.10 | 7.0 | 275 | 13.3 |
| 90 | 24 | 0.38 | 4.5 | 1.49 | 0.11 | 7.0 | 253 | 12.3 |

formed with industrial plants and a large quantity of olive paste. Nevertheless, the diminution didn't exceed 10-20% [19-24]. Quite on the contrary, when the experiments were performed using small laboratory plants and a small quantity of olive (1-10 kg), the reduction of the total phenol content and induction time value of oil as a result of an increased malaxation time exceeded 50-60% [25-29].

Different results are due to different test conditions and, in particular, to the protective action of a large quantity of olive paste with regard to the oxidative activity of enzymes and air during the malaxation step when industrial decanters are used. In that case only a small part of olive paste is in contact with the atmosphere at the surface, while the remaining part, being under the surface, is protected from the oxidant ambient due to the presence of phenolic substances.

The malaxation time also influences the composition of the volatile substances of oils, as is reported in some investigations performed with plants on a laboratory scale [25, 26, 28-30] or in industrial olive oil mills [23]. Results are, generally, in agreement and show a more or less pronounced increase in total volatile compounds when the malaxation time is prolonged (Tab. 7) [23].

**Tab. 7.** Average content of some and total volatile compounds of oils obtained by a centrifugal decanter at water saving from olive paste of different cultivars malaxed for different times [23].

| Volatile compounds | Malaxation time | | |
|---|---|---|---|
| [mg/kg] | 15 min | 45 min | 90 min |
| n-Octane | 5.8 | 8.0 | 8.8 |
| Ethyl acetate | 4.8 | 7.0 | 5.4 |
| Ethyl alcohol | 34.8 | 35.0 | 35.6 |
| 1-Penten-3-one | 15.2 | 20.4 | 19.6 |
| Hexanal | 22.8 | 21.6 | 26.2 |
| Isobutyl alcohol | 7.2 | 8.6 | 9.0 |
| 1-Penten-3-ol | 18.8 | 22.6 | 24.2 |
| Isoamyl alcohol | 16.0 | 17.2 | 18.8 |
| *trans*-2- Hexenal | 301.8 | 298.4 | 309.2 |
| 1-Hexanol | 10.6 | 13.8 | 16.2 |
| *cis*-3-Hexen-1-ol | 3.8 | 4.4 | 5.0 |
| *trans*-2-Hexen-1-ol | 18.8 | 23.2 | 31.6 |
| Acetic acid | 1.6 | 3.6 | 3.4 |
| Total volatile compounds | 502.4 | 530.6 | 567.2 |

The temperature of olive paste during the malaxation is also important, it may influence oil extraction yield and some characteristics of virgin olive oil. Fig. 1 shows the increase in oil yields obtained with a 3-phases centrifugal decanter of olive paste malaxed at different temperatures [20]. These results are in agreement with those reported in other papers [3, 18].

Increasing the temperature of olive paste up to 32 °C during the malaxation step did not influence the free fatty acids percentage and peroxide value of oil [20]. The total phenol content of oil can only change when the temperature of olive paste during malaxation increases. However, differing results are reported in the literature concerning this subject. In some investigations, performed with small laboratory plants, is noted that an increase in the temperature of olive paste during the malaxation step favours a reduction of the total phenol content of oil [25-27, 29]. In other investigations, performed in industrial olive oil mills, just the opposite was found [20, 21, 24, 31-33]. In that case it is evident that the results obtained from tests performed on a laboratory scale are sometimes not useful to predict the results which will be obtained in an industrial olive oil mill.

The temperature of olive paste malaxation also influences the composition of the volatile compounds of virgin olive oil [25, 26, 29]. When the temperature of malaxation rises, the most evident effects are an increase in the concentrations of *trans*-2-hexenal, hexan-1-ol and *trans*-2-hexen-1-ol and a decrease in the concentration of $C_6$ esters and *cis*-3-hexen-1-ol [29].

Of course, the variation of time and temperature of the malaxation of olive paste does not influence the composition of the fatty acids, sterols, aliphatic and triterpene alcohols, triterpene di-alcohols, waxes, diglycerides and triglycerides fractions of virgin olive oil. However, if the temperature is higher than 50-60 °C, some substances, like waxes, aliphatic alcohols and triterpene di-alcohols can become more soluble in the oily phase increasing their concentration in the oil [34]. In that case, it is possible that the content of these substances (waxes and triterpene di-alcohols) exceeds the limit values established by the law [35]. The latter are used to distinguish virgin olive oil, obtained by mechanical means, from pomace olive oil, obtained by solvent extraction and refining of oil contained in olive pomace.

## 5 Liquid and solid-phases separation

Virgin olive oil is the oil obtained from malaxed olive paste using mechanical means only. This oil alone, among other vegetable oils, is edible immediately after extraction provided that the olives were of the right ripe, sound and of good quality.

Virgin olive oil is extracted in olive oil mills with pressure, centrifugation and percolation systems by using different apparatus driven by physical forces which, when correctly exerted on olive paste, enable the separation of the different phases of olives, liquid and solid.

Applying pressure is the oldest and still wide-spread system used to extract virgin olive oil. It is based on the principle that when the olive paste will release the oily must (olive oil + vegetable water) if it is is pressed under the right conditions. The oily must can be separated from the solid phase (pomace) with the help of the drainage effect of the mats and stone fragments.

Percolation, or selective filtration, is another old system still used. The first studies to build a machine to work olives with this method date back to 1911; in 1951 the “Alfin” prototype was built (now called Sinolea). It takes advantage of the different surface tensions of the liquid phases in the paste. To this end a steel plate is plunged into olive paste. When it is withdrawn again, it will be coated with oil because of the different surface tensions. In the past, the percolation system was coupled with pressures [36], while at present it is coupled with the centrifugal decanter [37].

Finally, centrifugation is a world-wide-spread continuous system based on the centrifugal force applied on olive paste, diluted with lukewarm water. The dilution increases the difference between the specific weights of the immiscible liquids (oil and vegetable water) and the solid matter.

In the past, some investigations were carried out to ascertain the quantitative results obtained with new centrifugal decanters [38] in comparison with those obtained with pressure [37, 39, 40] and with percolation-centrifugation systems [37]. Tab. 8 [41] shows the quantitative results obtained in many tests carried out in industrial olive oil mills equipped with both, pressure and 3-phases centrifugation systems. The data show that both systems give good yields and generate by-products with a normal content of oil.

**Tab. 8.** Average values of extraction yields and some qualitative characteristics of by products obtained using different systems to process olives [41].

| Determinations | Pressure | 3-phases centrifugation |
|---|---|---|
| Extraction yield [%] | 85.6 | 85.1 |
| Pomace | | |
| Moisture [%] | 27.9 | 51.2 |
| Oil [%] | 7.7 | 4.2 |
| Oil [% of dry matter] | 10.7 | 8.7 |
| Vegetable water | | |
| Dry residue [%] | 16.4 | 9.0 |
| Oil [g/l] | 6.7 | 12.5 |
| Oil [% of dry matter] | 4.1 | 14.1 |

The different systems used to process olives may influence some qualitative characteristics of virgin olive oil (Tab. 9) [42]. The data show that no significant differences in the content of free fatty acids, peroxide value, UV absorptions and organoleptic assessment occurred, due to the different extraction systems. These results, also reported in another paper [43], confirm that the commercial qualitative parameters depend on the quality of olives and on possible enzymatic alteration of olive fruits.

Whereas some authors point out that the phenol content of oils was significantly effected by the extraction systems [26, 40-43], others state just the reverse [31, 44]. The natural antioxidants content (phenols) of virgin olive oil extracted by the 3-phases centrifugation was significantly lower than that of oil extracted with either pressure or percolation systems. This occurs because lukewarm water is used (40-60 l/100 kg of olives) to dilute the olive paste before extraction with the centrifugal decanter. Water lowers the concentration of phenols in the aqueous phase because of dilution and diminishes the concentration of phenols in the oily phase because of a partition equilibrium [41, 45, 46]. Neither in pressure nor in percolation systems water is added to olive paste.

However, the phenol content of virgin olive oil depends on the crushing method, malaxation conditions and water addition [41-42] during the separation of oily must by the vertical centrifuge. These reasons may explain the differ-

**Tab. 9** Average values of qualitative characteristics of virgin olive oils obtained from good quality olives processed by different systems [42].

| Determinations | Pressure | 3-phases centrifugation | Percolation |
|---|---|---|---|
| Free Fatty Acids [%] | 0.23 | 0.22 | 0.23 |
| Peroxide value [meq$O_2$/kg] | 4.0 | 4.9 | 4.6 |
| $K_{232}$ | 1.93 | 2.01 | 2.02 |
| $K_{270}$ | 0.12 | 0.12 | 0.12 |
| Organoleptic assessment (score) | 6.9 | 7.0 | 7.0 |
| Total phenol [mg/l as gallic acid] | 158 | 121 | 157 |
| Induction time [h] | 11.7 | 8.9 | 11.2 |
| Chlorophyll pigments [mg/kg] | 5.0 | 9.1 | 8.9 |

ent results obtained concerning the phenol content of oils extracted by pressure or centrifugation systems [31, 44].

The induction time is significantly lower in olive oils extracted with a 3-phases centrifugal decanter than in oils extracted with either pressure or percolation systems. The reason being that this parameter is positively correlated with the total phenol content [47].

On the other hand, the chlorophyll pigments content was higher in oil extracted with 3-phases centrifugal decanter than in oils extracted with another system. The reason is the use of a metallic crusher to prepare olive paste.

When poor quality olives are industrially processed with either pressure or 3-phases centrifugation systems, the results may differ (Tab. 10) [42]. A significant difference in the content of free fatty acids occurs when oil is extracted with a centrifugal decanter. Generally, oil of a better quality is obtained in this way than with a pressure system. No significant differences were found in phenol content and induction time, because oils from low-quality olives have a lower phenol content, regardless of the extraction system employed [42, 43].

The system used to process olives and the quality of olive fruits also affect the content of several volatile and aromatic substances of oils (Tab. 11) [48-50]. The data show that oils obtained by a pressure system have a higher content of some volatile compounds, like *n*-octane, 2-methyl-1-propanol, 3-methyl-1-butanol, acetic acid and ethyl acetate, than oils produced with a centrifugal decanter. These compounds are decomposition products of hydroperoxides (*n*-octane) [51] and from fermentation (alcoholic, lactic and acetic) products that are formed in the olive paste which remains on mats. The latter are employed when a pressure system is used.

Compared to that oils obtained with a centrifugal decanter always have a lower content of the above-mentioned

**Tab. 10.** Average values of qualitative characteristics of virgin olive oils obtained from poor quality olives processed with different systems [42].

| Determinations | Pressure | 3-phases centri-fugation |
|---|---|---|
| Free fatty acids [%] | 1.40 | 1.03 |
| Peroxide value [meq$O_2$/kg] | 8.5 | 11.1 |
| $K_{232}$ | 2.09 | 2.12 |
| $K_{270}$ | 0.13 | 0.14 |
| Organoleptic assessment (score) | 6.2 | 6.5 |
| Total phenol [mg/l as gallic acid] | 87 | 91 |
| Induction time [h] | 5.7 | 6.5 |
| Chlorophyll pigments [mg/kg] | 6.6 | 4.9 |

compounds, in particular when very ripe and poor quality olives are processed. This explains why this system is applied wherever the quality of olives is – due to a lack of cultivation practices – rather poor.

The 3-phases centrifugal decanter has many advantages, compared to the pressure system, but also some drawbacks; like the addition of lukewarm water to olive paste (40-60 l/100 kg of olives), that causes a lower content of natural antioxidants in the oil and an increase in the volume of vegetable water. It is possible to reduce these drawbacks by recycling vegetable water as soon as it is produced and to use it instead of ordinary lukewarm water to dilute the olive paste which enters the decanter [5, 52]. The results obtained by applying this technique show a reduction of 35-40% in the volume of vegetable water and an increase of about 30% in the total phenol content of oil [5, 52].

However, in the early nineties a new centrifugal decanter was launched on the market with the object of avoiding or

**Tab. 11.** Average content [mg/kg] of some volatile compounds of oils obtained from good and poor quality olives processed by pressure and 3-phases centrifugal decanters [46].

| Volatile compounds [mg/kg] | Good quality olives | | Poor quality olives | |
|---|---|---|---|---|
| | Pressure | 3-phases centrifugation | Pressure | 3-phases centrifugation |
| n-Octane | 24.3 | 7.1 | 177.8 | 34.5 |
| Ethyl acetate | 13.5 | 6.8 | 114.8 | 18.3 |
| Ethyl alcohol | 56.3 | 58.1 | 58.1 | 44.0 |
| 1-Penten-3-one | 2.7 | 9.1 | 0.4 | 2.2 |
| Hexanal | 41.3 | 36.1 | 21.3 | 18.1 |
| 2-Methyl-1-propanol | 20.1 | 4.0 | 124.3 | 24.4 |
| 3-Methyl-1-butanol | 78.6 | 10.9 | 306.0 | 51.1 |
| *trans*-2- Hexenal | 425.5 | 435.4 | 33.0 | 32.1 |
| 1-Hexanol | 107.3 | 35.6 | 51.1 | 9.9 |
| *cis*-3-Hexenol | 39.6 | 27.0 | 18.5 | 4.5 |
| *trans*-2-Hexenol | 97.5 | 39.9 | 23.7 | 10.2 |
| Acetic acid | 6.0 | 1.7 | 32.6 | 14.5 |
| Total volatile compounds | 987.0 | 748.0 | 1017 | 320.5 |

reducing the quantity of water added to olive paste and the volume of vegetable water [5, 21, 53-56]. Besides the conventional 3-phases centrifugal decanters the following ones are utilised in olive oil mills: i) 2-phases centrifugal decanter, type integral, that operates without adding lukewarm water to olive paste and separates oil and pomace (65-72% of moisture) by 2 flow exits only (widespread in Spain); ii) 2-phases and half centrifugal decanter, type optional or "water saving", that operates by adding 0-30 l of lukewarm water per 100 kg of olive paste and separates oil, pomace (55-60% of moisture) and vegetable water (5-30 l/100 kg of olives) by 3 flow exits (quite common in Italy).

Tab. 12 [54] shows the quantitative results obtained in olive processing by the new centrifugal decanter set to "water saving" and by a conventional 3-phases centrifugal decanter. The data show that the new decanter, set to water saving, gave satisfactory oil yields, comparable with those obtained with a 3-phases decanter, and a volume of vegetable water (about 8 l/100 kg of olives) smaller than that obtained with a 3-phases decanter (about 96 l/100 kg of olives).

The different types of centrifugal decanters also influence the qualitative characteristics of oil [5, 21, 53-61]. Tab. 13 [56] shows the average values of some qualitative characteristics of oils obtained with 2- and 3-phases centrifugal decanters. The data show that the qualitative commercial parameters (free fatty acids, peroxide value, specific spectrophotometric absorptions in the UV region and organoleptic assessment) did not change significantly when good quality olives were processed with either centrifugal decanter. The total phenol and *o*-diphenol content and induction time of oils obtained with the 3-phases centrifugal decanter were lower than those of oils extracted by 2-phases centrifugal decanter [5, 21, 53, 54, 57-61]. This is due to the addition of lukewarm water (40-60 l/100 kg of olives) to olive paste processed with a 3-phases centrifugal decanter.

**Tab. 12.** Average values of extraction yields and some qualitative characteristics of by-products obtained from olive processing with 2- and 3-phases centrifugal decanters [54].

| Determinations | 2-phases centri-fugation | 3-phases centri-fugation |
|---|---|---|
| Extraction yield [%] | 86.1 | 85.1 |
| <u>Pomace</u> | | |
| Quantity [kg/100 kg olives] | 72.5 | 50.7 |
| Moisture [%] | 57.5 | 52.7 |
| Oil [%] | 3.16 | 3.18 |
| Oil [% of dry matter] | 7.44 | 6.68 |
| <u>Vegetable water</u> | | |
| Quantity [l/100 kg olives] | 8.3 | 97.2 |
| Dry residue [%] | 14.4 | 8.5 |
| Oil [g/l] | 13.4 | 12.6 |
| Oil in by-products [kg/100 kg olives] | 2.42 | 2.80 |

**Tab. 13.** Average values of qualitative characteristics of virgin olive oils obtained from good quality olives processed with 2- and 3-phases centrifugal decanters [56].

| Determinations | Centrifugal decanter | |
|---|---|---|
| | at 2-phases (water saving) | at 3-phases |
| Free fatty acids [%] | 0.34 | 0.32 |
| Peroxide value [meq$O_2$/Kg] | 4.3 | 4.7 |
| $K_{232}$ | 1.56 | 1.50 |
| $K_{270}$ | 0.11 | 0.10 |
| Organoleptic assessment (score) | 7.2 | 7.2 |
| Total phenol [mg/l as gallic acid] | 292 | 197 |
| *o*-Diphenol [mg/l as caffeic acid] | 278 | 149 |
| Induction time [h] | 14.2 | 11.0 |
| Chlorophyll pigments [mg/kg] | 6.9 | 7.5 |

**Tab. 14.** Average content [mg/kg] of volatile compounds of virgin olive oils obtained by centrifugal decanter at two- and three-phases [56].

| Volatile compounds | 2-phases decanter | 3 phases decanter |
|---|---|---|
| n-Octane | 7.6 | 6.8 |
| Ethyl acetate | 5.8 | 6.1 |
| 2-Methyl butanal | 3.6 | 3.4 |
| 3-Methyl butanal | 3.8 | 3.8 |
| Ethyl alcohol | 47.2 | 38.8 |
| Pentan-3-one | 19.4 | 18.7 |
| 1-Penten-3-one | 23.1 | 19.5 |
| Hexanal | 32.5 | 32.8 |
| Isobutyl alcohol | 9.1 | 7.2 |
| *trans*-2-Pentenal | 2.9 | 2.2 |
| 1-Penten-3-ol | 22.1 | 16.9 |
| Isoamyl alcohol | 20.7 | 16.6 |
| *trans*-2-Hexenal | 275.0 | 253.0 |
| n-Amyl alcohol | 1.8 | 1.3 |
| 2-Penten-1-ol | 14.2 | 10.4 |
| 1-Hexan-1-ol | 19.0 | 17.1 |
| 3-Hexen-1-ol | 8.3 | 6.6 |
| t-2-Hexen-1-ol | 26.5 | 29.1 |
| Acetic acid | 12.0 | 8.4 |
| 1-Octane-1-ol | 4.0 | 4.4 |
| 2-Butan-1-one | 9.3 | 10.5 |
| Total content | 567.9 | 513.6 |

Tab. 14 [56] shows the composition of volatile compounds in oils obtained from good quality olives by 2- and 3-phases centrifugal decanters. The data show that the content of single and total volatile compounds did not change significantly when the different types of decanter were used.

Of course, the oils obtained from the same lot of olives by 2- and 3-phases centrifugal decanters or by other systems have the same composition of fatty acids, sterols, aliphatic and triterpene alcohols, tocopherols, waxes, steroid hydrocarbons and other compounds of the unsaponifiable fraction. These substances are very soluble in oil and only sparingly soluble in water, and for this reason, their content does not change when a different quantity of water (from 0 to 60 l/100 kg of olives) is added to olive paste. However, some papers [21, 61] confirm the above-mentioned findings while others [58, 62] present conflicting results. In fact, *Ranalli* and *Angerosa* [58] pointed out that in some cases the stigmastadienes content and the $\Delta_7$-stigmastenol percentage were higher than the legal limit values [35] for virgin olive oil, due to the different decanter employed or to olive cultivar. On the other hand, *Koutsaftakis* et al. [62] stated that the different systems employed to process olives affected the percentage of many sterols in oils significantly. They derived the results from multivariate statistical analyses. In reality, the average values of the percentage of each sterol reported were quite similar and the differences negligible. The analytical data showed that all oils contained a higher percentage of campesterol than the legal limit value (≤4.0%) allowed [35] for virgin olive oil, and in some oils the percentage of total apparent β-sitosterol was lower than the legal limit value (≥93.0%).

Looking at the above-mentioned results, it is possible to affirm that the only disadvantage of the new centrifugal decanters, integral type or set to water saving, is their giving a wetter pomace. But they have many advantages: they reduce the quantity of lukewarm water added to olive paste, give oils with higher content of natural antioxidants and reduce the volume of vegetable water and the costs for its disposal.

Over the last 50 years, the number of olive oil mills and the systems employed have changed, so started the spreading of the centrifugal decanter in the late sixties. In 1998, the number of systems and the different systems adopted in olive oil mills working in the countries of the Mediterranean area were those specified in Tab. 15 [63]. The data prove that the centrifugal decanter is widespread in Spain, especially the 2-phases type, and in Greece, especially the 3-phases type, while the traditional pressure system is still used and employed in 40% of the Italian olive oil mills.

**Tab. 15.** Number of olive oil mills working in the different countries of Mediterranean area and olive processing systems employed [63].

| Country | Artisan olive oil mills | Hydraulic pressure | | Centrifugation | | Total† |
|---|---|---|---|---|---|---|
| | | P<200 kg/cm² | P>200 kg/cm² | 3-phases | 3 exits (with little water) | |
| Spain | – | | 63 | 194 | 1743 | 2000 |
| Italy | | 200 | 3000 | 3000 | 750 | 6950 |
| Greece | | | 450 | 2000 | 200 | 2650 |
| Tunis | | 875 | 585 | 340 | 10 | 1810 |
| Syria | 105 | 61 | 440 | 167 | | 668 |
| Portugal | | 200 | 820 | 85 | 25 | 1130 |
| Morocco | 10,000 | 8000 | 1500 | 15 | | 9515 |
| France | 14 | 32 | 102 | 42 | 8 | 184 |
| Algeria | 630 | 630 | 915 | 140 | | 1685 |
| Cyprus | | | | 20 | 2 | 22 |
| Israel | 2 | 4 | 27 | 34 | | 65 |

† Artigianal olive oil mills are not considered.

## 6 The use of co-adjuvants in olive processing

As determined in Soxhlet's apparatus oil yields generally vary between 80-87% of the oil content of olive fruits in industrial olive oil mills. If olive paste is difficult to work, the oil yield will diminish to 70-80%, because of the higher quantity of "not free" oil. The latter is due to oil trapped in the colloidal tissues of cytoplasm or to oil emulsified with vegetable water. In that case, it is possible to improve the oil yield by using some co-adjuvants, like mineral talc and enzymes, which are useful to increase the quantity of "free oil" in olive paste.

The use of micronised natural talc (MTN) is allowed in Spain, likewise the use of enzymatic compounds, the former is added at levels of 1-2% to olive paste processed in centrifugal decanters. The results of tests carried out by using this co-adjuvant [4, 64-67] indicated that talc is useful to improve the performance of the centrifugal decanter and also oil yields. Furthermore, it helps to obtain cleaner oil, which is qualitatively similar to that extracted from non-treated olive paste. The talc ends up in the pomace because of its high specific weight (2.8 g/cm³) and the oil is free of this substance.

Many papers were published in the past [68-71] and also recently [72-79], about the use of enzymes, with pectolitic activity, in olive processing applying the different systems. The results obtained indicated that the use of enzymatic co-adjuvants helps to improve oil yields (Tab. 16) [72]. Some authors reported that the commercial quality and the composition of fatty acids, sterols, aliphatic and triterpene alcohols, triterpene dialcohols and other fraction of the unsaponifiable matter of oil are not influenced by the use of enzymatic products [72, 75-76].

**Tab. 16.** Data obtained from processing of olive paste by treatment with enzymes by 3-phases centrifugal decanter [72].

| Test n° | Oil content of olives [kg/100 kg olives] (Soxhlet) | Oil yield [kg/100 kg olives] | | Yield increase using enzymes [kg/100 kg olives] |
|---|---|---|---|---|
| | | Control | With enzymes | |
| 1 | 26.61 | 19.21 | 19.58 | +0.37 |
| 2 | 23.84 | 17.41 | 18.21 | +0.80 |
| 3 | 24.96 | 17.25 | 18.11 | +0.86 |
| 4 | 20.06 | 15.41 | 15.45 | +0.04 |
| 5 | 20.41 | 14.62 | 16.31 | +1.69 |
| 6 | 21.08 | 16.62 | 16.98 | +0.36 |
| 7 | 28.41 | 23.50 | 24.24 | +0.74 |

However, conflicting results were reported by others, in some cases, oils obtained from good quality olive paste, treated or not treated with enzymes, contained amounts of campesterol [77], stigmastadienes [78] and waxes [79] that were higher than the legal limit value [35]. These results appear unusual and dangerous for the image of virgin olive oil. But if they were confirmed they would indicate that the enzymatic products may have a remarkable biochemical activity which enables them to affect olive paste to change the composition of some oil components, and thus their concentration in the oil. The latter is important to distinguish virgin olive oil from other vegetable oils, as established by the EC law [35].

The EC Commission has the purpose to prohibit the use of technological co-adjuvants in olive oil mills that impairs definition and image of virgin olive oil. The unusual above-mentioned results may help the Commission to make a decision concerning the use of co-adjuvants in olive processing.

## 7 Separation of liquid phases

The oily must obtained with the different extraction systems has to undergo one last operation to separate virgin olive oil completely from vegetable water. The separation of two immiscible liquids with different specific weight is possible by natural decantation (settling) or by centrifugation.

Natural decantation is a slow process in which the oil is in contact with the vegetable water for a long time with the consequent risk of contamination. This method is adopted only in some regions of different countries, where the quality of olive fruits is rather poor and consequently, the quality of oil is poor, too.

The centrifugation of oily must using a vertical centrifuge with a rotatory speed of 6500-7000 rpm, is, on the contrary, a very quick operation which requires little labour and separates impurities and oil effectively. This method is widespread in the world and used whenever good quality virgin olive oil is wanted.

The vertical centrifuges used in the past needed to be stopped periodically to permit manual cleaning of the cones as they become clogged with the residual solids present in the oily must. However, this drawback is overcome in modern self-cleaning centrifuges which automatically discharge the sediment when in operation by activating a control that opens a series of peripheral holes in the drum.

In small olive oil mills, equipped with 1 or 2 presses, it is possible to use a vertical centrifuge which has to be cleaned manually to separate the oily must, because the vegetable water obtained with a pressure system generally contains only a small amount of solids in the suspension. On the other hand, in olive oil mills, with a large working capacity or equipped with 3-phases centrifugal decanters, only self-cleaning vertical centrifuges are used to separate the oily must because the vegetable water obtained with this system contains a significant quantity of solids.

The automatic discharge of the sediment, when repeated correctly and at the right time, ensures that only a very small amount of oil is lost. The reason being that the aqueous sediment contains almost exclusively pieces of olive flesh in which only oil is present that is “not free” and not extractable by mechanical means. The automatic self-cleaning vertical centrifuge separators have a high hourly capacity and can be programmed for their cleaning at established times (every 10, 15 or more minutes) with an automatically discharge.

In olive oil mills equipped with 2-phases centrifugal decanters (type integral), the oily phase is formed of 97-98% of oil and 2-3% of solid impurities and vegetable water. To clean this oil better in the vertical centrifuge, a quantity of lukewarm water (from 1:1 to 1.5:1 v/v, water/oil) is generally added, especially in Spain. This determines a production of 15-25 l of aqueous by-product per 100 kg of olives

**Tab. 17.** Variation of some characteristics of virgin olive oil obtained by a pressure system when water is added to oily must during the separation by vertical centrifuge [41, 42].

| System | Water added to oily must [%] | Free fatty acids [%] | Peroxide value [meq$O_2$/kg] | Total phenols [mg/l] | Induction time [h] |
|---|---|---|---|---|---|
| Pressure | - | 0.18 | 4.0 | 156 | 9.8 |
| Pressure | 40 | 0.23 | 4.7 | 129 | 8.3 |
| Pressure | 80 | 0.24 | 4.9 | 115 | 8.0 |
| Percolation | - | 0.21 | 3.9 | 147 | 9.5 |
| 3-Phases-centrif. | - | 0.16 | 4.7 | 103 | 7.8 |

and a decrease in the phenol content, induction time and bitterness of the oil [79].

In Italy, on the other hand, the cleaning of oily must obtained by pressure, 3-phases or 2-phases (water saving) centrifugal decanters, is performed in the vertical centrifuge separator without adding water. This is due to the simultaneous separation of the mixture, oil and vegetable water. Furthermore, this method provides the opportunity to avoid a decrease in the phenol content of oils (Tab. 17) [41, 42].

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