The Italian modern oil mill: extraction efficiency, olive oil quality, diversification, and sustainability

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In the last two decades, Italian oil mill modified its structures assuming a more industrial aspect, yet assuring good yields, olive oil quality and an economic and sustainable utilisation of the by-products. The modern oil mill adopts the continue centrifugation system, two- or three-phase, and carries out the crushing of olives by the metallic crushers, having different characteristics able to influence the oil yield and the organoleptic properties of virgin olive oil. The following operation of olive paste malaxation, if carried out at rational time and temperature, favours the coalescence phenomenon and "frees" most of the oil contained in the cell vacuoles, allowing to extract up to 85-86% of the oil contained in olive fruits, without a negative effect on olive oil quality. Then, olive paste is sent to the centrifugal decanter to separate virgin olive oil from the aqueous and solid phases (decanter at 3 phases) or from the solid phase only (decanter at 2 phases). Some oil mills, having a larger loading capacity, with the end to increase oil extraction yield, carry out the double extraction of olive oil, using another specific decanter. Moreover, several oil mills have also the machine able to separate the stone fragments from olive pomace with the end to utilize them as fuel. Finally, oil mill equipped with the three phases centrifugal decanter utilizes the liquid by-product (oil mill wastewater) as fertiliser of the soil, in particular, by its controlled spreading on olive grove. In the region where there aren't industrial structures to extract pomace oil, oil mill can utilise the wet olive pomace spreading it on cultivated soil, of course, after the separation of the stone fragments.

INTRODUCTION

In Italy, the restructuring of the industrial machines of olive oil mill started at the end of 1960s, with the partial replacement of the traditional press by the continuous centrifugal decanter. The same trend was followed later in Spain, but it was rather fast, as proved by the total replacement of the pressing system, with the 3-phases centrifugation system, within the end of 1980s. In Italy, instead, the change was slower and actually some oil mills are still equipped with the presses, whereas most of oil mills carry out the extraction of oil from olives by centrifugal decanter. Today, all Spanish oil mills adopt the 2-phase decanter, instead the 3-phase decanter is mostly used in Italy. This is due to the Italian law in force which allows using the oil mill liquid by-product (oil mill wastewater) as a fertliser of agricultural soil by its controlled spreading on an olive grove, or on another cultivated soil. In Italy, most oil mills have a small-medium size, and many of them are private (more than 95%) and process olives on behalf of third parties, processing separately the olive batches of each olive grower and, therefore, carrying out a service for which they are payed. Only few oil mills, instead, have a cooperative structure, contrarily to what happens in Spain, where the number of oil mills is lower than the Italian ones, and most of them have a cooperative structure and a very large size. Anyway, the Italian sector is well organised and equipped with effective machines able to assure high oil yield and also a very good quality of oil, because olive farmers are used to picking olives when they are not ripe, when they are green-yellow or begin to turn dark. Today, a problem of Italy is the reduction of olive production (Table I), due in part to the neglect of the culture, especially in some areas in South Italy, where the rational cultivation of olive grove was not possible because of the size and structure of old and too tall olive trees. Other reasons are the size of olive farms, in general too small to assure a right income to the farmer, also due to the high cultivation costs, or the European subsidies to the oil production, regardless of the production of olive fruits. Another problem of Italian oil mills is the selling of olive pomace, their solid by-product, because the industrial sector of olive pomace manifacturing is enduring a crisis due to the reduction of the consumption of olive pomace oil in many countries. Moreover, the production costs of pomace oil increased due to the strict regulations on industrial safety and on environment protection, and to the characteristics of raw material (olive pomace from a centrifugal decanter, two- or three-phase) that is very wet and with a low oil content. For these reasons, some oil mills, with the aim to recover the lost income (non-sale of olive pomace to the industry), tried to increase the oil yield, by a second extraction of oil using another decanter, and to recover, via a stoner machine, the wooden fragments of the pomace, to use as fuel. Therefore, the current Italian way to process olives in an oil mill is as described below.

FIRST OPERATIONS AFTER OLIVE PICKING: OLIVE STORAGE, LEAF-REMOVAL AND OLIVE WASHING

Olive farmers carry olives every day, using suitable means, to the oil mill where olives are stored in the bins, the large plastic cases able to contain about 300 kg of olives. This is a right way to store olives, waiting for their process, because it helps avoiding that the olives heat due to the presence of leaves, to small layers of olives, not above 30-40 cm, or to holes in the bins which are useful for air to go through. Moreover, the use of bins allows storing and processing the olives of each farmer separately, as they want the oil of their olives, a very common usage in Italy. Finally, the method allows storing 1.5-2.0 t of olives, taking up a small surface (only 1 m^2).

The following operations, represented by the removal of leaves and the washing of the olives, are carried out via a machine that separates the leaves by means of a strong suction, due to an aspirator pump. The presence of leaves with olives during the crushing operation, carried out using the metallic crushers, affects the organoleptic properties of oil increasing the content of the trans-2-hexenal, having a pleasant aroma of fresh cut grass, as reported in some papers [1-2]. The content of phenolic compounds of oil, instead, doesn't change because their concentration in

Table I - Production (t x 1000) of virgin olive oil in the different countries of the Mediterranean Sea

COUNTRY	Year 2015-16	Year 2016-17	Year 2017-18	Year 2018-19	Year 2019-20	Average 2015-19
Spain	1403	1291	1282	1790	1125	1378
Italy	474	182	429	174	366	325
Greece	320	195	346	185	275	264
Portugal	108	69	135	100	140	110
France	5.4	3.3	6.2	5.8	3.4	4.8
Cyprus	6.0	6.0	6.0	4.7	4.3	5.4
Croatia	5.5	5.0	3.9	3.4	4.1	4.4
Slovenia	0.5	0.4	0.4	0.9	0.3	0.5
Morocco	130	110	140	200	145	145
Algeria	82	63	82	97	128	90
Tunisia	140	100	325	140	440	229
Egypt	16.5	30.0	38.5	41.0	40.0	33.2
Libya	18.0	16.0	18.0	16.0	17.0	17.0
Israel	18.0	18.0	17.0	14.0	19.0	17.2
Palestine	21.0	20.0	19.5	15.0	39.5	23.0
Lebanon	23.0	25.0	17.0	17.5	14.0	19.3
Syria	110	110	100	154	118	118
Jordan	29.5	20.0	21.0	21.0	34.5	25.2
Turkey	150	178	283	193	230	207

Source: Document IOC. Session of November 2021 the olive paste and in the leaves is almost equal, as reported in the mentioned paper [1]. After the removal of the leaves, the same machine carries out the washing of olives via a forced flow of water useful to remove all the mineral material, as sand, earth, stones, and dust. Moreover, the washing operatiion allows to remove possible residue of pesticides, or their metabolites, if any.

OLIVE PASTE PREPARATION

When the oil mill is equipped with the pressing system, which is not that common nowadays, it is better to use the granite millestones to have an olive paste with a granulometry suitable for a better yield and an organoleptic quality of oil that is more appreciated by the traditional consumers. When the oil mill is equipped with the centrifugation system, now very widespread in Italy, the preparation of olive paste is carried out by the metallic crusher, consisting of a revolving body at high speed and a fixed part, generally consisting of a grid with holes having a diameter variable between 5 and 7 mm. The metallic crushers have a high hourly working capacity and the most common are those with fixed hammers, discs, and knives, fixed or mobile. The crushing operation, carried out by the different metallic crushers, is very important because it can influence the oil yield and the organoleptic quality of virgin olive oil as well. In particular, the variable characteristics of the metallic crushers are the speed of the revolving body, that can be changed between 1000 and 2500 (or more) rpm, and the diameter of holes of the grid. In general, when the preparation of olive paste is carried out at high speed and with a grid having small holes, it is possible to obtain an increasing of oil yield and an oil with a greater content of the phenolic compounds, in particular the secoiridoides, and, therefore, more bitter, and pungent. Continuing, the results of some studies [3, 4], carried out to ascertain the influence of the use of millstones and the metallic crushers to prepare olive paste, have indicated that the use of the metallic crusher helped to obtain an olive oil with a higher content of total phenols, thus more bitter and pungent.

OLIVE PASTE MALAXATION

The olive paste obtained after the crushing operation, carried out by the metallic crushers, is generally emulsified due to the strength with which the revolving elements crush the olives at high speed through the small holes of the grid. The emulsified oil is difficult to separate from the solid olive paste causing, therefore, a reduction of oil extraction yield. To obtain satisfying yields it needs to reduce, or remove, the emulsion by a suitable operation of malaxation, carried out at right temperature, between 24 and 30°C, and for a time variable between 30 and 60 minutes. The malaxation consists in a slow movement of olive paste that helps the small drops of oil merge into larger drops [5] and form a continuous liquid phase, the free oil, easy to separate from other phases by the centrifugal decanter. The malaxation operation carried out in an industrial oil mill, adopting the suggested values of time and temperature, helps increase oil yield and doesn't influence the commercial quality of olive oil [6-8], as shown in the Tables II [6] and III [7]. In particular, the oil oxidation does not occur because the oxygen in the olive paste is consumed by the oxidation of phenols (lesser part) and by the respiration of microrganisms (greater part), as verified in a specific paper [9]. The commercial quality of virgin olive oil depends above all on the soundness of the olives, whereas its organoleptic quality depends on the cultivar and, above all, on the ripening degree of the olives and on the adopted crushing method.

Table II - Average values of some qualitative parameters of oils obtained by a 3-phases centrifugal decanter from olive pastes mixed for different times in an open mixer

Determinations	**Malaxation time (minutes)**		
	15	**45**	**90**
Free fatty acids (%)	0.42^{a}	0.43^{a}	0.41^{a}
Peroxide value (meq/kg)	5.4^{a}	5.3^{a}	5.3^{a}
K_{232}	1.50^{a}	1.51^{a}	1.51^{a}
K_{270}	0.11^{a}	0.11^{a}	0.11^{a}
Organoleptic assessment (score) *	7.2^{a}	7.2^{a}	7.2^{a}
Total phenols (mg/L, as gallic acid)	269^{a}	267^{a}	225^{b}
Induction time (Rancimat) (hours)	12.9^{a}	12.5^{a}	11.5^{a}
Chlorophyill pigments (mg/kg)	5.9^{a}	5.9^{a}	5.8^{a}

* Values variable between 1 and 9; extra virgin olive oil: score ≥ 6.5
Different letters along the same row indicate significant differences ($P \leq 0.05$)

Table III - Variation of some qualitative parameters of oils obtained by a 2-phases centrifugal decanter from olive pastes (cv. Cornicabra) malaxed for 60 minutes at different temperatures

Determinations	**Malaxation temperature (°C)**		
	20	**28**	**40**
Free fatty acids (%)	0.21^{a}	0.21^{a}	0.25^{a}
Peroxide value (meq/kg)	5.9^{a}	6.2^{a}	6.8^{a}
K_{232}	1.60^{a}	1.67^{a}	1.70^{a}
K_{270}	0.14^{a}	0.15^{a}	0.16^{a}
Total phenols (mg/kg)	450^{a}	650^{b}	788^{c}
o-Diphenols (mg/kg)	205^{a}	326^{b}	390^{c}
Oxidative stability Rancimat (hours)	14.7^{a}	21.8^{b}	24.7^{c}
α-Tocopherol (mg/kg)	205^{a}	219^{b}	221^{b}
β-Carotene (mg/kg)	0.63^{a}	0.87^{b}	1.56^{c}
K_{225}	0.46^{a}	0.52^{b}	0.56^{c}

Different letters along the same row indicate significant differences ($P \leq 0.05$)

SEPARATION OF OIL FROM OLIVE PASTE

In Spain, the extraction of oil from olives has been carried out only by the centrifugation system for over thirty years, first by the three-phase centrifugal decanter and, since the end of the past century, only by at the two-phase one that does not produce wastewater. As said before, the replacement of the pressing system was slow in Italy, but today most of oil mills carry out the oil separation from the malaxed olive paste by the continuous centrifugation system, as in other countries of the Mediterranean basin. However, in Italy the three-phase decanter is the method used the most, because it allows an easier control of the efficiency and the performance of the plant when it needs to process many batches of olives, belonging to different farmers and with different rheological characteristics, separately. Moreover, the use of the three-phase centrifugal decanter is also preferred because it is possible to utilise the oil mill wastewater to fertilise the agricultural soil, as permitted by the Italian law in force (Law 574/1996). Several published papers have highlighted the good quantitative, qualitative, and economic results obtained by using the three and two-phase centrifugation system and, therefore, it is possible to state that the Italian oil mill sector has reached an optimum technological standard. In fact, the centrifugation system does not cause a pollution of oil which may preserve all the original characteristics depending, above all, on the quality of the olives. Even more so occurs when the two-phase decanter is used, because it doesn't need to add water to olive paste, and, therefore, the obtained oil will have the maximum content of phenolic compounds, some of which are partially water-soluble, as shown in Table IV [10]. However, when the two-phase centrifugal decanter is used, it needs to reduce the hourly loading of olive paste into the decanter to obtain a satisfying oil yield. That is due to the viscosity of the olive paste (too high because not diluted by adding water) that causes the reduction of the sedimentation rate of the solid phase and, as consequence, the increase of the corresponding sedimentation time [11]. To assure the efficiency of the process, the time of the olive paste into the decanter needs to be extended by reducing its hourly loading to a value equal to 50-60% of the theoretical capacity suggested by the manufacturer. When the oil mill processes olives by the two-phase decanter, the non-extracted oil remains into the solid by-product and, sometimes, its percentage may be too high, especially when the amount of olive paste that is sent hourly to decanter is excessive. This often happens when the oil mill has to process large amount of olives and needs to feed the decanter with a high quantity of olive paste every hour. These circumstances that occur mainly in the countries that have a high olive production, suggested to recover, in the same oil mill, part of oil by means of a further immediate centrifugation of the partially deoiled olive paste, coming from the first extraction. The aim of the second extraction of oil from the olive paste (in the same oil mill) is just that of obtaining a higher oil yield for the benefit of the olive grower. Of course, this process is expensive and, therefore, could be convenient only for a large size oil mill, especially for a cooperative oil mill as it needs to process a large amount of olives on a daily and yearly base. This explains why it is more common in Spain and not widespread in other countries. In Italy, infact, only a few oil mills, private or a cooperative, carry out the double extraction of oil from olives by centrifugation of olive paste. Not many papers have been published on the theme of the double extraction of oil from olives by the centrifugation system [12-18] and the obtained results have generally indicated that the amount of the recovered oil was small (0.3-0.7 kg/100 kg olives) and that a possible anomaly in the percentage of triterpene dialcohols and in the content of waxes of oil might occur. The average quantitative results of some tests, carried out by processing many and big batches of olives in three different large size oil mills (Oil Mill A, B and C), where the double extraction of oil was carried out by two and three-phase centrifugal decanter are (in short) reported in Table V [13, 15, 18]. The data indicate that the total extracted oil varied between 87.0 and 87.5% of the oil content of olives and the oil lost in the by-products varied between 2.4 and 2.6 kg/100 kg of olives. The average oil yield of the first extraction was 19.3 kg/100 kg of olives, whereas the average recovered oil of the second extraction was 0.54 kg/100 kg of olives. However, that last value is an indication only and refers to the mentioned specific test, because it depends, above all, on the oil yield obtained in the first extraction, that, when high, causes, of course, a lower value of the oil yield of the second extraction. Anyhow, the recoverd oil, even if small in quantity, represents an important income for the oil mill, and for the olive grower, when the total amount of olives daily processed is very high. With reference to the chemical-physical characteristics of the oils extracted in the mentioned test, Table VI [13, 15, 18] reports the average values of some parameters

Table IV - Phenolic composition (mg/kg) of oils (cv Coratina) obtained by the centrifugal decanter at 2 and 3-phases in an industrial oil mill

Determinations	**Centrifugal decanter working at**	
	2-phases	**3-phases**
3,4-DHPEA	0.87	0.58
p-HPEA	3.7	2.3
3,4-DHPEA-EDA	522	427
p-HPEA-EDA	78.2	67.3
3,4-DHPEA-EA	352	245
Total phenols (mg/kg, as 3,4-DHPEA) *	673	585
Induction time (hours)	17.8	15.5

* Evaluated by the colorimetric method

Table V - Results obtained in three oil mills of Puglia region where the double extraction of oil, from cv. Coratina olives, was carried out by the decanter at three-phases (Oil Mill A), by the decanter at two-phases (Oil Mill B) and by the decanter at two-phases (1st extraction) and at three-phases (2nd extraction) (Oil Mill C)

<table>
<tr><td rowspan="3">Oil Mill A</td><td colspan="2">Olives</td><td colspan="2">Oil Yield %</td><td colspan="2">Olive pomace</td><td colspan="2">Oil Mill Wastewater</td><td colspan="2" rowspan="2">Oil lost in the by-products *</td></tr>
<tr><td>H_2O %</td><td>Oil %</td><td>1st Extract.</td><td>2nd Extract.</td><td>H_2O %</td><td>Oil %</td><td>Dry Matter</td><td>Oil g/L</td></tr>
<tr><td>45.2</td><td>23.2</td><td>85.3</td><td>2.2</td><td>47.6</td><td>2.29</td><td>9.6</td><td>12.2</td><td colspan="2">2.62</td></tr>
<tr><td rowspan="3">Oil Mill B</td><td colspan="2">Olives</td><td colspan="2">Oil Yield %</td><td colspan="2">Olive pomace 1st Extract.</td><td colspan="2">Olive pomace 2nd Extract.</td><td colspan="2" rowspan="2">Oil lost in the by-products *</td></tr>
<tr><td>H_2O %</td><td>Oil %</td><td>1st Extract.</td><td>2nd Extract.</td><td>H_2O %</td><td>Oil %</td><td>H_2O %</td><td>Oil %</td></tr>
<tr><td>48.4</td><td>24.0</td><td>83.7</td><td>3.4</td><td>62.8</td><td>4.00</td><td>68.7</td><td>2.8</td><td colspan="2">2.50</td></tr>
<tr><td rowspan="3">Oil Mill C</td><td colspan="2">Olives</td><td colspan="2">Oil Yield %</td><td colspan="2">Olive Pomace</td><td colspan="2">Oil Mill Wastewater</td><td rowspan="2">Oil lost *</td><td rowspan="2">Recoverd Stone *</td></tr>
<tr><td>H_2O %</td><td>Oil %</td><td>1st Extract</td><td>2nd Extract.</td><td>H_2O %</td><td>Oil %</td><td>Dry Matter %</td><td>Oil g/L</td></tr>
<tr><td>50.5</td><td>21.2</td><td>85.6</td><td>1.4</td><td>59.5</td><td>3.00</td><td>10.4</td><td>18.5</td><td>2.4</td><td>12.6</td></tr>
</table>

*Value calculated and expressed as kg/100 kg olives

Table VI - Average characteristics of virgin olive oils of first and second extraction obtained by processing olives (cv Coratina) in oil mills A, B and C located in Puglia region (I)

Oil Mill	Extraction	Free fatty Acids (%)	Peroxide Value (meq/kg)	K_{232}	K_{270}	Total Phenols (mg/kg)	Total Sterols (mg/kg)	Waxes (mg/kg)	Erythrodiol + Uvaol (%)
A	First	0.23	3.1	1.29	0.070	136	---	---	1.7
	Second	0.29	5.3	1.40	0.103	116	---	---	5.2
B	First	0.62	7.8	1.38	0.121	310	1204	45	3.9
	Second	0.86	10.6	1.64	0.197	420	1995	95	9.8
C	First	0.18^a	5.4^a	1.60^a	0.14^a	306^a	1060^a	31.6^a	3.1^a
	Second	0.26^b	6.5^b	1.78^b	0.18^b	366^b	1590^b	53.4^b	8.5^b

Different letters along the same row indicate significant differences ($P \leq 0.05$)

generally controlled to know the qualitative characteristics of oils and, therefore, their commercial category. Moreover, only to ascertain other possible effects of the technical conditions adopted in the second extraction, Table V also reports the average values of the total content of phenols, sterols, waxes and percentage of erythrodiol + uvaol of oils. The data indicate that the values of the qualitative commercial parameters of oils of second extraction were significantly higher than those of oils of the first extraction. However, they were consistent with the limit values established for olive oil of extra virgin category. The average values of the content of total phenols, sterols and waxes and the percentage of the triterpene di-alcohols of the second extraction oils were also significantly higher than those of the first extracted oils. However, only the percentage of erythtrodiol + uvaol was higher than the legal limit (4.5%) established for virgin olive oil. At this point, it needs to highlight that the oil obtained in the second extraction is a virgin olive oil because it is extracted in the oil mill from olive paste by mechanical means only, and, therefore, it can be mixed with other virgin olive oils, per choice of the oil mill manager. To verify the characteristics of the mixture of oils extracted in the first and second centrifugation, the oils, obtained in oil mill C were mixed in the same percentage obtained in the mechanical industrial process. The analytical results of the final mixture are reported in Table VII [19]. The data indicate that the blend of oils obtained from the first and second extraction, has the caracterstics of an extra virgin olive oil, and it couldn't be otherwise because of the very small amount of oil obtained in the second centrifugation. Therefore, the oil of the second mechanical extraction may be mixed with that of the first extraction if the obtained blend does not cause an alteration of the commercial category. Of course, it is interest of the oil mill responsible to avoid a worsening of the commercial quality of virgin olive oil because it would lead to a reduction of its economic value.

Table VII - Average characteristics of virgin olive oils obtained in the first and second centrifugation of olive pastes and those of oil obtained by blending the two oils in the same ratio obtained in oil mill

Determinations	**Oil of 1st extraction**	**Oil of 2nd extraction**	**Blend of oils of 1st and 2nd extraction**
Free fatty acids (%)	0.18^{a}	0.26^{b}	0.20
Peroxide value (meq/kg)	5.4^{a}	6.5^{b}	5.4
K_{232}	1.60^{a}	1.78^{b}	1.60
K_{270}	0.14^{a}	0.18^{b}	0.14
Total phenols (mg/kg)	306^{a}	366^{b}	307
Chlorophyll pigments (mg/kg)	39^{a}	217^{b}	41
Total sterols (mg/kg)	1060^{a}	1590^{b}	1065
Erythrodiol + Uvaol (%)	3.1^{a}	8.5^{b}	3.2
Waxes (mg/kg)	31.6^{a}	53.4^{b}	32.0

Different letters along the same row indicate significant differences ($P \leq 0.05$)

Table VIII - Characteristics of olive pomace obtained by the different olive processing systems

Determinations	**Pressing**	**3-phases Centrifugation**	**2-phases Centrifugation**
Amount (kg/t olives)	250-350	450-550	800-850
Moisture (%)	22-35	45-55	65-75
Oil (% on fresh matter)	6-8	3.5-4.5	3.0-4.0
Fiber (%)	20-35	15-25	10-15
Stone fragments (%)	30-45	20-28	15-18
Ash (%)	3-4	2-4	3-4
Nitrogen (mg/100 g)	250-350	200-300	250-350
Phosphorus (mg/100 g)	40-60	30-40	40-50
Potassium (mg/100 g)	150-200	100-150	150-250
Total phenols (mg/100 g)	200-300	150-250	400-600

UTILIZATION OF OLIVE POMACE

Olive pomace is the solid by-product obtained in the oil mill when olives are processed using various systems, the pressing or two- or three-phase centrifugation. The chemical composition of olive pomace is variable and depends, above all, on olive characteristics and on the mechanical system used to extract virgin olive oil. A possible composition of olive pomace is reported in Table VIII [19]. Until the end of the past century, the olive pomace obtained in the oil mill was sold to the industry of olive pomace to produce pomace oil and the de-oiled and dry residue, useful as a fuel. As said, in Italy the mentioned industry has reduced its activity and the oil mill tried to otherwise utilize olive pomace with the aim to recover the lost income. Today, many oil mills, by a suitable stoner machine, carry out the separation of stone fragments from the flesh of olive pomace, coming from the three- or two-phase decanter, with the aim to use them as fuel. The amount of the recovered stones depends on the size of stone fragments of olive pomace and on the diameter of holes of the stoner machine used. The results obtained in a specific test [20], carried out by taking olive pomace samples from different oil mills, indicated that the amount of recovered stone fragments was 12.5 and 15.3 kg/100 kg olives, when olive pomace was, respectively, obtained by the three- or two-phase decanter. A similar result (12.6 kg/100 kg olives) was obtained in the test carried out in oil mill C (Table V) and reported in a specific paper [18]. Olive stones are constituted of lignin, a complex polymeric chemical compound, having a tridimensional structure and formed from phenolic substances (phenol-alcohols). As reported in other paper [21], the chemical composition (on dry matter) of olive stone fragments is the following: Carbon 49.7%; Hydrogen 7.02%; Oxygen 43.0%; Nitrogen 0.041%; Sulphur 0.020%: Chlorine 0.22%. Other chemical-physical characteristics of stone fragments, freshly obtained from the stoner machine, are the following [20]: moisture 19.5-20.8%; oil 0.27-0.49%; ash 0.31-0.39%. Similar results were obtained and reported in the aforesaid paper [21]: moisture 22%; oil 0.46%; ash 0.20%. Moreover, the most important property of stone fragments is the calorific value, resulting, on average, 4117 kcal/kg [20], close to the value of 18.2 MJ/kg, reported in the mentioned paper [21]. Finally, the olive stone fragments, used as fuel, have the important characteristic to produce, while burning, a negligible amount of ash, as residue, and traces of sulphured and nitrogenous gas (dioxides) only in the smoke.

Wet olive pomace obtained by the centrifugal decanter at the two- and three-phases can be utilised as an amendment and fertiliser of the agricultural land, by its controlled spreading on the cultivated soil, as permitted by the Italian law n. 574/1996. Some papers have been published on this topic, [22-26], important are the results obtained in a specific test and reported in Table IX [27]. The data indicate that spreading 50 t/ha of wet olive pomace, obtained by a three-phase decanter, on the olive grove allowed to significantly increase, in the fourth year of treatment, the olive production from 17.8 kg/tree (control) to 22.0 kg/tree (treated plots with 50 t/ha of olive pomace). Moreover, the values of other parameters also positively increased, as Table IX shows. In the light of what is reported in this mentioned test [27], it is possible to state that similar or better results could be obtained by spreading, on the olive grove, the wet and stoned olive pomace from the two-phase decanter. This is because it also contains the liquid phase of the olive paste, where a large part of organic water-soluble substances, like sugars, acids, pectins, phenols, mineral salts, etc., very important for the fertility of soil, are solved.

Table IX - Results obtained in olive trees cultivation (cv. Leccino) on soil treated, for 4 consecutive years, with 50 t/ha of fresh olive pomace (3-phases dec.)

Determinations		**1° year**	**2° year**	**3° year**	**4° year**
Olives production (kg/tree)	Control	5.8	8.0	11.8	17.8
	50 t/ha	7.2	10.0	16.0	22.0
Productive efficiency (kg olives/m^3 foliage)	Control	0.5	0.65	0.82	1.25
	50 t/ha	0.6	0.90	0.95	2.35
Olive dry weight (g)	Control	0.72	0.95	0.65	0.70
	50 t/ha	0.88	1.10	0.80	0.75

In the last years, it has been suggested to add wet olive pomace to other liquid and solid vegetable waste to treat in the biological purification plants, based on the anaerobic digestion, able to produce bio-methane also. That solution on one hand represents a form of disposal of a waste without any benefit to the agricultural sector and useful only for few oil mills, on the other it takes away to the agriculture a natural resource useful to fertilize the cultivated soil or to utilize as renewable source of thermal energy.

UTILISATION OF OIL MILL WASTEWATER

Oil mill wastewater (OMW) is the liquid by-product obtained when oil mill processes olives by the pressing system or by the centrifugal decanter at three-phases. The chemical composition of OMW is variable not only in consequence of the employed mechanical system but also for the influence of olive cv, its ripening degree and the different technical operations adopted in oil mill, in particular the amount of water added to olive paste. A possible composition of OMW is reported in Table X [19]. Many papers were published on the theme of purification and/or utilization of OMW, as reported in a specific book [28], but the proposed solutions, generally based on the concentration or the destruction of the natutral organic substances present in OMW, never had a practical use because the results were

Table X - Amount and characteristics of oil mill wastewater (OMW) obtained in olive processing by the different systems adopted in oil mill

Determinations	**Adopted system to process olives**		
	Pressing	**3-phases Centrifugation**	**2-phases Centrifugation**
Amount (L/t olives)	400-500	600-800	100 *
pH	4.5-5.7	4.5-6.0	4.5-5.0
Dry residue (%)	8-20	4-15	1.4-2.0
Organic matter (%)	6-16	3-12	1.3-1.9
Oil content (%)	0.2-0.8	0.6-2.0	0.5-0.6
C.O.D. (g O_2/L)	60-200	50-170	10-12
Total phenols (g/L) **	2-10	2-8	0.5-1.6
Ash (%)	2-4	1-3	0.1
Nitrogen (%)	0.10-0.15	0.05-0.10	---
Phosphorus (%)	0.05-0.10	0.02-0.06	---
Potassium (%)	0.2-0.5	0.1-0.3	---

* Water used to wash oil in the vertical centrifuge; **Expressed as caffeic acid.

Table XI - Average results obtained by spreading OMW on soil cultivated with olive trees for 9 consecutive years

Determinations	**Control plot**	**Plot treated with 30 L OMW/m^2 ***
Olive production (kg/tree)	5.7	6.5
Oil content of olives (%)	17.5	17.7
Phenols content of oil (mg/kg)	196	206
Characteristics of the soil Organic matter (g/100 g)	1.77	2.18
Total nitrogen (g/100 g)	0.11	0.13
Available P (mg/kg, as P_2O_5)	34	53
Exchangeable K (mg/kg, as K_2O)	250	265
Reducing substances (mg/100 g)	0.12	0.42
Total microflora (CFU/g of soil)**	3.0 x 10^8	5.9 x 10^9

*Plot not fertilized; ** CFU: Colonies Forming Units

partial and the cost too high, in particular for the energy requested from the studied processes. Other researches, instead, were carried out with the aim to re-use OMW in agriculture, by its recycling on the soil cultivated with herbaceous [29-32] or arboreal plants [33-41]. Among the test carried out on herbaceous cultivations, very important were the results reported in a paper [29] in which OMW, from a three-phase decanter, was spread on soil cultivated with maize for 5 years. The average maize production was 8301 kg/ha, in the plots treated with 200 L OMW/m^2 and not fertilised, whereas the production of the control plots, normally fertilised by chemical fertilisers, was 7714 kg/ha. Similar results were obtained in a specific test, as reported in another paper [32] and shown in Figure 1, where the significant increase of the biomass production of the plots treated with 50 L OMW/m^2 and not fertilised (on average 40.7 kg/plot) is pointed out, with respect to that of the control plots, normally fertilised by chemical synthetic fertilisers (on average 32.4 kg/plot).

However, more interesting tests were carried out by reusing and spreading OMW on soil cultivated with trees. The results obtained spreading OMW on soil cultivated with old olive trees have indicated, as reported in another paper [36], that the average olive

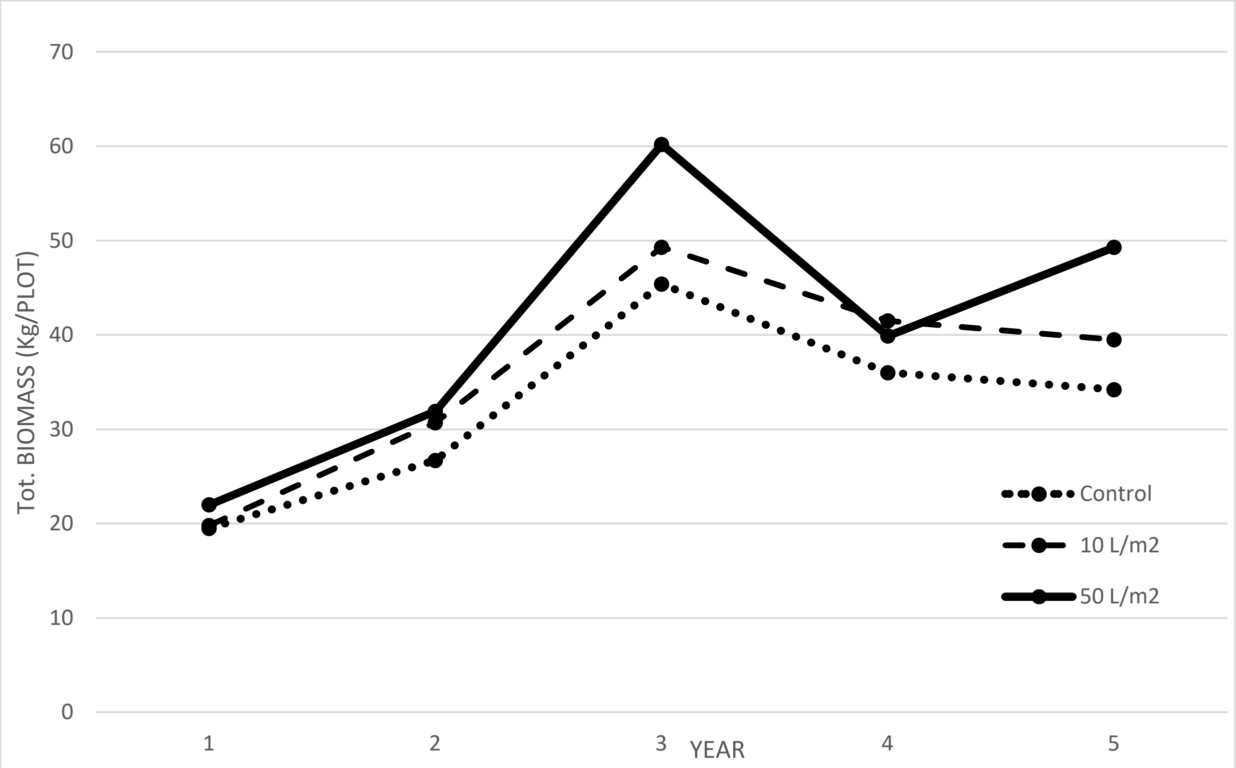

Figure 1 - Results obtained (total biomass) in the maize cultivation (5 consecutive years) on soil treated with different amount of olive mill wastewater (OMW)

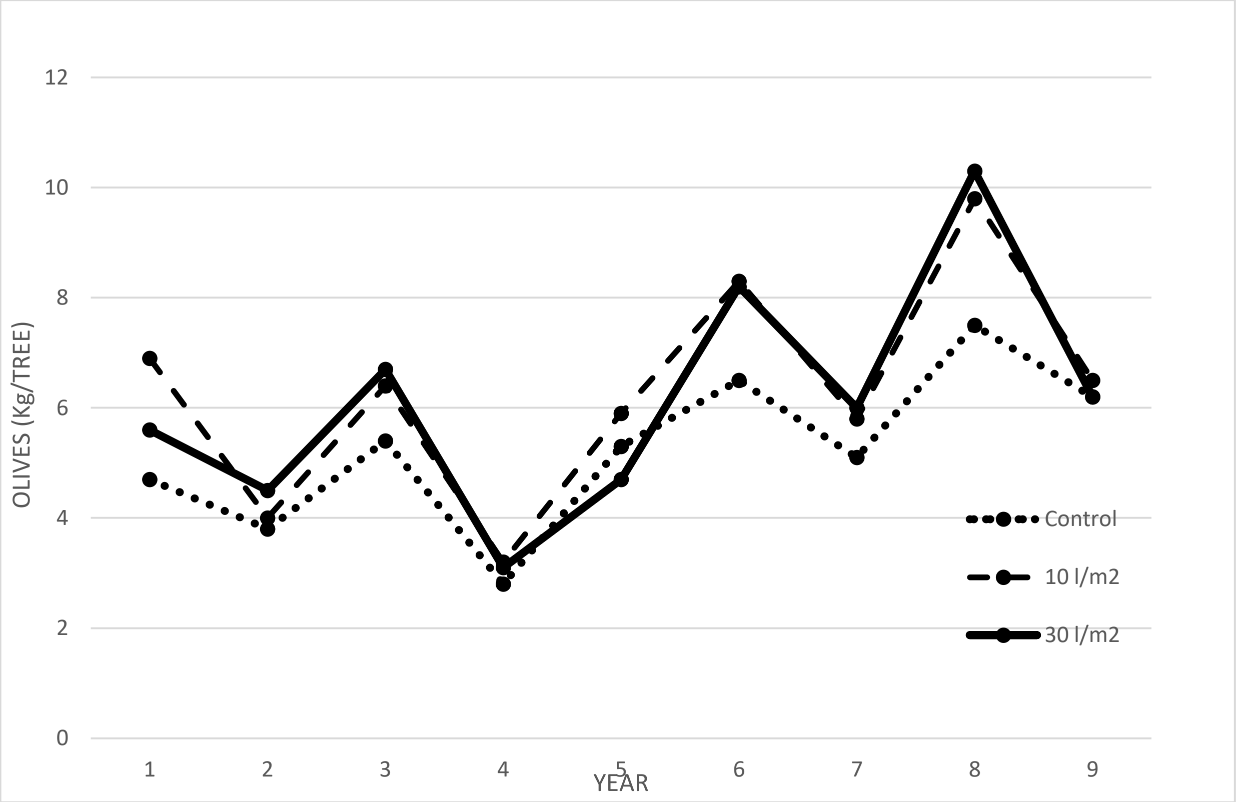

Figure 2 - Olives production in olive trees cultivation (9 consecutive years) on olive orchard treated with different amount of olive mill wastewater (OMW)

production of the plots treated with 100 m^3 OMW/ha was 510 kg/ha, whereas the olive production of the control plots was, on average, 345 kg/ha. On the same subject, the results of a specific test, carried out spreading OMW on soil cultivated with young olive trees and reported in another paper [40] and in Figure 2, have shown that the average olive production (9 consecutive years) of the plots treated with 30 L OMW/m^2 and not fertilised was 6.5 kg/tree, whereas the olive production of the control plots, normally fertilised, was, on average, 5.7 kg/tree, as shown in Table XI. Even though the average olive production wasn't significantly different, it is importanrt to point out that the spreading of OMW allowed avoiding the use of chemical fertilisers. Moreover, the results obtained at the end of the test have shown that the values of some characteristics of the soil of plots treated with OMW were similar or better than those ascertained on the control plots, as reported in the same Table XI [40]. Another interesting test was carried out to ascertain the effects of OMW spread on soil cultivated with a vineyard [41]. The results obtained at the end of the test showed that the average production (11 consecutive years) of grapes for the plots treated with 50 L OMW/m^2 and not fertilised was 30.2 kg/grapevine, whereas the grapes production of the control plots, normally fertilised with chemical fertilisers, was 22.5 kg/grapevine, as reported in the paper [41] and in Figure 3. Moreover, the values of some characteristics of grapes, grape juice and soil were similar or better than those ascertained on the control plots, as reported in Table XII.

The good results obtained by spreading OMW on cultivated soil are due to the supply of mineral and organic matter contained in the liquid by-product of oil mill when olives were processed by pressing and three-phase centrifugation systems. Table XIII reports the amount of chemical and natural (OMW) fertilisers supplied to the soil cultivated with olive grove, previously described [40]. The data indicate that the treatment with 30 L OMW/m^2 supplies to the soil, with respect to the standard fertilisation of control plots, more nitrogen (about twice), the same amount of phosphorus, more potassium (4-5 times) and more than 17 t/ha of dry organic matter. These data explain the same (or higher) olive production of olive trees cultivated in the soil plots treated with the largest amount of OMW and not fertlised. Moreover, it is important to point out that, at the end of the test, after 9 consecutive years of treatment, the chemical and micro-biological characteristics of the soil, treated with 30 L OMW/m^2, were similar or better (significant difference) than those of the control plots. In particular, the increase of the reducing substances of the soil treated with OMW, as shown in Tables XI and XII seems interesting. This is due to the phenols supplied with OMW that, on time, oxidise and polymerise forming substances with similar properties of humic

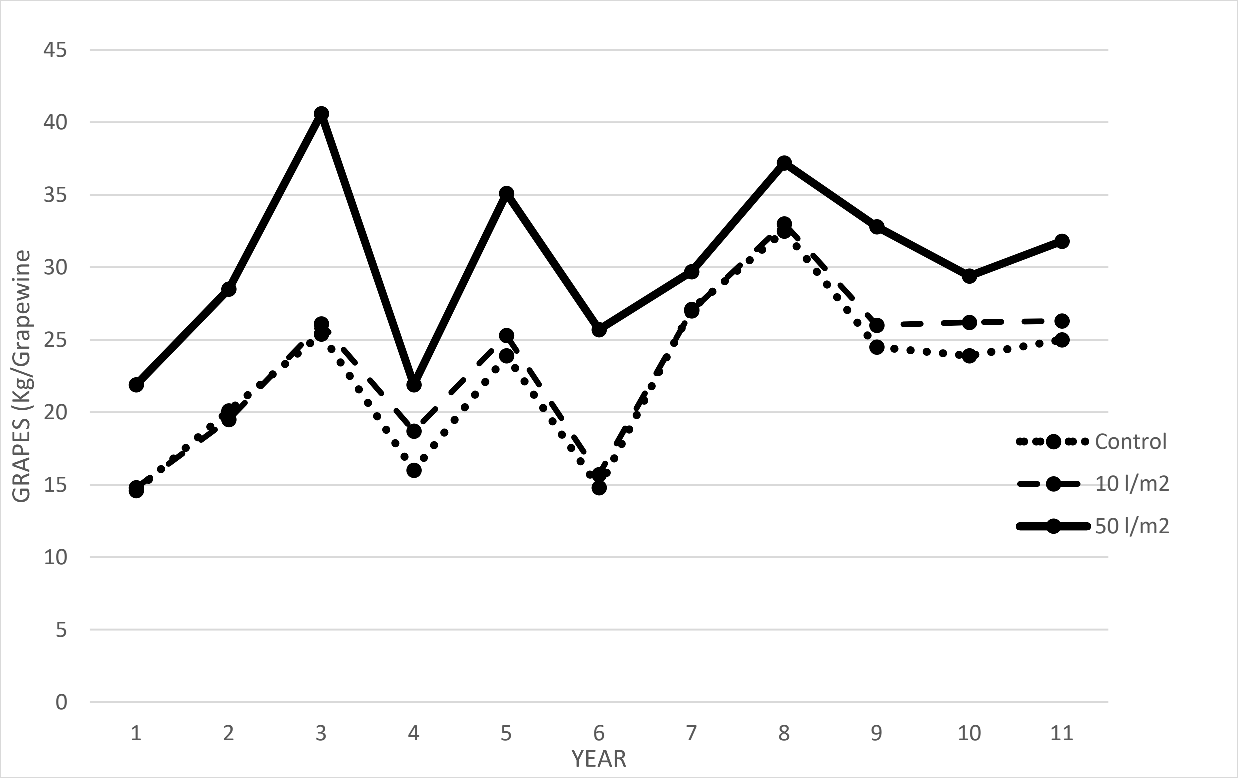

Figure 3 – Grapes production in the grapevine cultivation (11 consecutive years) on soil treated with different amount of olive mill wastewater (OMW)

Table XII - Average results obtained spreading OMW on soil cultivated with grapevine for 11 consecutive years

Determinations	**Control plot**	**Plot treated with 50 L OMW/m^2 ***
Grapes production (kg/grapevine)	22.5	30.2
Sugars content of grape-juice (%)	15.5	15.7
Organic acidity of grape-juice (g/L)	7.8	8.0
Characteristics of the soil Organic carbon (%)	0.94	1.13
Total nitrogen (g/100 g)	0.10	0.13
Available P (mg/kg, as P_2O_5)	45.4	88.0
Exchangeable K (mg/kg, as K_2O)	244	330
Reducing substances (mg/100 g)	0.17	0.65
Saprobic fungi (CFU/g of soil)**	10^7	10^8

*Plot not fertilized; **CFU: Colonies Forming Units

Table XIII - Dry organic matter and mineral nutritious elements supplied to soil, cultivated with olive grove, by the chemical fertilization and by the controlled spreading of OMW (3-phases decanter)

Parameters	**Control**	**Oil Mill Wastewater (OMW)**		
		5 L / m^2	**10 L / m^2 ***	**30 L / m^2 ****
Dry organic matter (kg/ ha)	--	2960	5920	17760
Nitrogen (kg/ ha, as element)	46 + 25	71 + 25	35.5 + 50	150
Phosphorus (kg/ ha, as element)	50	50 + 7.5	25 + 15	45
Potassium (kg/ ha, as element)	100	100 + 80	50 + 160	480

*Partially fertlized; **Not fertilized

and fulvic acids [42-43], confirming the results of other studies [44-49] which have ascertained that the phenolic compounds are the precursors in the synthesis of humic substances. These new substances still have a reducing power and are very useful for agriculture because they increase the fertility of soil.

Finally, it is important to point out that the recycling of OMW, and the fresh wet fiber of olive pomace, on the cultivated soil is a practice that accomplishes the concept of sustainable agriculture because it utilises a natural product coming from the agriculture that leads, not only to an increase of the production of arboreal and herbaceous cultivations, but also to an improvement of the chemical and micro-biological properties of the soil. Moreover, the recycling of the by-products of oil mill on cultivated soil, from which they derive, is an example of circular economy because it helps to avoid the use of chemical synthetic fertilisers and, as a consequence, reduces the cost of agricultural activity.

BIBLIOGRAPHY

[1] L. Di Giovacchino, F. Angerosa, L. Di Giacinto, Effect of mixing leaves with olives on the organoleptic quality of oil obtained by centrifugation. J. Am. Oil Chem. Soc. 73, 371-374, (1996)

[2] R. Malheiro, N. Rodrigues, C. Bissaro, F. Leimenn, S. Casal, E. Ramalhosa, J.A. Pereira, Improvement of sensorial and volatile profiles of olive oil by addition of olive leaves. Eur. J. Lipid Sci. Technol. 119 (11), 1700177 (2017)

[3] F. Angerosa, L. Di Giacinto, Caratteristiche di qualità dell'olio di oliva vergine in relazione ai metodi di frangitura. Nota II. Riv. Ital. Sostanze Grasse 72, 1-4, (1995)

[4] F. Caponio, V. Alloggio, T. Gomes, Phenolic compounds of virgin olive oil: influence of paste preparation techniques. Food Chemistry 64, 203-209, (1999)

[5] J. M. Martinez Moreno, C. Gomez Herrera, C. Janer del Valle, Estudios fisico-quimicos sobre las pastas de aceitunas molidas. IV. Las gotas de aceite. Grasas y Aceites 8, 112-118, (1957)

[6] L. Di Giovacchino, N. Costantini, M. L. Ferrante, A. Serraiocco, Influence of malaxation time of olive paste on oil extraction yields and chemical and organoleptic characteristics of virgin olive oil obtained by a centrifugal decanter at water saving. Grasas y Aceites 2, 179-186, (2002)

[7] A.M. Inarejos-Garcia, A. Gomez-Rico, M. Desamparados Salvador, G. Fregapane, Influence of malaxation conditions on virgin olive oil yield, overall quality, and composition. Eur. Food Res. Technol. 228, 671-677, (2009)

[8] E. Boselli, G. Di Lecce, R. Strabbioli, G. Pieralisi, N.G. Frega, Are virgin olive oil obtained below 27 °C better than those produced at higher temperature? Food Science and Technol. 42, 748-757, (2009)

[9] A. Parenti, P. Spugnoli, P. Masella, L. Calamai, Utilizzo dell'anidride carbonica emessa dalle olive durante la trasformazione per migliorare la qualità dell'olio. Primo contributo-Prove di laboratorio, Riv. Ital. Sostanze Grasse 82, 283-290, (2005)

[10] G. De Stefano, P. Piacquadio, M. Servili, L. Di Giovacchino, V. Sciancalepore, Effect of extraction system on the phenolic composition of virgin olive oil. Fett/Lipid 9, 328-332, (1999)

[11] P. Amirante, P. Catalano, Analisi teorica e sperimentale dell'estrazione dell'olio d'oliva per centrifugazione. Riv. Ital. Sostanze Grasse 70, 329-335, (1993)

[12] L. Di Giovacchino, L'estrazione dell'olio dalle olive mediante doppia lavorazione. Nota I: risultati ottenuti con l'abbinamento pressione-centrifugazione. Riv. Ital. Sostanze Grasse 68, 83-90, (1991)

[13] L. Di Giovacchino, N. Costantini, L'estrazione dell'olio dalle olive mediante doppia lavorazione: Nota II: risultati ottenuti con la doppia centrifugazione. Riv. Ital. Sostanze Grasse 68, 519-527, (1991)

[14] J. Alba Mendoza, F. Hidalgo Casado, A. Ruiz Gomez, F. Martinez Roman, J. Moyano Perez, A. Cert Ventulà, C. Perez Camino, V. Ruiz Mendez, Caracteristicas de los aceites de oliva de primera y segunda centrifugacion. Grasas y Aceites 47, 163-181, (1996)

[15] L. Di Giovacchino, M.R. Mucciarella, N. Costantini, G. Surricchio, Double oil extraction from olive paste and olive pomace by centrifugal decanter at 2-phases, type integral. Riv. Ital. Sostanze Grasse 79, 351-355, (2002)

[16] P. Canamasas, L. Ravetti, Evaluation of second extraction of olive oil in Australia. Rural Industries Research and Development Corporation, Pubbl. n. 12/109, (2012)

[17] F. Caponio, G. Squeo, J.I. Monteleone, V.M. Paradiso, A. Pasqualone, C. Summo, First and second centrifugation of olive paste: influence of talc addition on yield, chemical composition and volatile compounds of the oils. Food Sci. and Technol. 64, 439-445, (2015)

[18] L. Di Giovacchino, S.M. Preziuso, M.G. Di Serio, M.R. Mucciarella, G. Di Loreto, B. Lanza, Double extraction of olive oil in large oil mills of Southern Italy: effects on extraction efficiency, oil quality and economy of the process. Eur. J. Lipid Sci. Technol. 119, Special Issue, 1600161, (2017)

[19] L. Di Giovacchino, Tecnologie di lavorazione delle olive in frantoio. Rese di estrazione e qualità dell'olio. Edagricole – Edizioni Agricole di New Business Media. Milano (2021)

[20] M.G. Di Serio, B. Lanza, E. Iannucci, F. Russi, L. Di Giovacchino, Valorization of wet olive pomace produced by 2 and 3-phases centrifugal decanter. Riv. Ital. Sostanze Grasse 88, 111-117, (2011)

[21] A. Leone, R. Romaniello, G. Peri, A. Tamborrino, Development of a new model of olive de-stoner machine: evaluation of electric consumption and kernel characterization. Biomass and Bioenergy 81, 108-116, (2015)

[22] U. Bing, E. Cini, A. Cioni, V. Laurendi, Smaltimento-recupero delle sanse di oliva provenienti da un “due fasi” mediante distribuzione in campo. L’Informatore Agrario 47, 75-78, (1994)

[23] R. Cardelli, C. Benitez, Change of chemical properties in two soils amended with moist olive residues. Agricoltura Mediterranea 128, 171-177, (1998)

[24] L. Di Giovacchino, C. Basti, N. Costantini, G. Surricchio, M.L. Ferrante, Riutilizzo in agricoltura dei sottoprodotti della trasformazione delle olive. In E. Cini, S. Regis, Smaltimento e riutilizzo di reflui dei frantoi, pp. 9-30, ARSIA, Regione Toscana (2000)

[25] E. Bonari, L. Ceccarini, Effetti della distribuzione di dosi crescenti di sanse umide sul terreno agrario. In E. Cini, S. Regis, Smaltimento e riutilizzo di reflui dei frantoi, pp. 31-57, ARSIA, Regione Toscana (2000)

[26] L. Di Giovacchino, C. Basti, L. Seghetti, N. Costantini, G. Surricchio, M.L. Ferrante, Effects of olive pomace spreading on soil cultivated with maize and grapevine. Agricoltura Mediterranea 134, 15-24, (2004)

[27] L. Nasini, G. Gigliotti, E. Federici, G. Cenci, P. Proietti, Effects of solid olive-mill waste amendment on soil fertility and olive (*Olea europea* L.) tree activity. Agriculture, Ecosystem and Environment 164, 292-297, (2013)

[28] M. Niaounakis and C.P. Halvadakis, Olive mill waste management, Literature review and patent survey. Typolito-George Dardanos, Athens, (2004)

[29] A. Garcia-Ortiz Rodriguez, J. Vicente Giraldez Cervera, P. Gonzalez Fernandez, R. Ordonez Fernandez, El riego con alpechin. Agricultura 730, 426-431, (1993)

[30] E. Bonari, M. Macchia, L.G. Angelini, L. Ceccarini, The wastewater from olive oil extraction: their influence on the germinative characteristics of some cultivated and weed species. Agricoltura Mediterranea 123, 273-280, (1993)

[31] F. Caporali, G. Anelli, R. Paolini, E. Campiglia, G. Benedetti, M. Contini, Crop application of treated waste waters from olive oil extraction. Agricoltura Mediterranea 126, 388-395, (1996)

[32] L. Di Giovacchino, C. Basti, N. Costantini, M.L. Ferrante, G. Surricchio, Effects of olive vegetable water spreading on soil cultivated with maize and grapevine. Agricoltura Mediterranea 131, 33-41, (2001)

[33] M. Catalano, T. Gomes, M. De Felice, T. De Leonardis, Smaltimento delle acque di vegetazione dei frantoi oleari. Inquinamento 2, 87-90, (1985)

[34] P. Proietti, A. Cartechini, A. Tombesi, Influenza delle acque reflue di frantoi oleari su olivi in vaso e in campo. L’Informatore Agrario 45, 87-91, (1988)

[35] K. Chartzoulakis, G. Psarras, M. Moutsopoulou, E. Stefanoudaki, Application of olive mill wastewater to a Cretan olive orchard: effects on soil properties, plant performance and the environment. Agriculture, Ecosystem & Environment 138, 293-298, (2010)

[36] S. Magdich, C. Ben Ahmed, M. Boukhris, B. Ben Ruina, E. Ammar, Olive mill wastewater spreading effects on productivity and oil quality of adult Chemlali olive (*Olea europea* L.) in the South of Tunisia. Intern. J. of Agronomy and Agricultural Research 6, 56-67, (2015)

[37] S. Magdich, C. Ben Ahmed, R. Jarboui, B. Ben Ruina, M. Boukhris, E. Ammar, Dose and frequency dependent effects of olive mill wastewater treatment on the chemical and microbial properties of soil. Chemosphere 93, 1896-1903, (2013)

[38] M. Catalano, M. De Felice, Utilizzazione delle acque reflue come fertilizzante. In Atti del Seminario Internazionale “Tecnologie e Impianti per il trattamento dei reflui dei frantloi oleari”, pp. 251-262, Lecce, 16-17 novembre 1989

[39] L. Di Giovacchino, C. Basti, N. Costantini, G. Surricchio, M.L. Ferrante, D. Lombardi, Effetti dello spargimento delle acque di vegetazione delle olive sul terreno coltivato con il mais e con la vite. Olivae 91, 37-43, (2002)

[40] B. Lanza, M.G. Di Serio, L. Di Giovacchino, Long-term spreading of olive mill wastewater on olive orchard: effects on olive production, oil quality and soil properties. Communications in Soil Science and Plant Analysis 48(20), 2420-2433, (2017)

[41] B. Lanza, M.G. Di Serio, L. Di Giovacchino, Microbiological and chemical modifications of soil cultivated with grapevine following agronomic application of olive mill wastewater, Water Air Soil Pollution 231:86, (2020)

[42] U. Tomati, E. Medejon, E. Galli, D. Capitani, A. Segre, Structural changes of humic acid during olive mill pomace composting. Comp. Scie. and Util. 9, 134-141, (2001)

[43] F. Alianiello, S. Trinchera, S. Dell’Orco, F. Pinzari, A. Benedetti, Somministrazione al terreno delle acque di vegetazione da frantoio: effetti sulla sostanza organica e sull’attiività microbiologica del suolo. Agricoltura Ricerca 173, 64-74, (1998)

[44] R. Vinken, A. Schaffer, R. Ji, Abiotic association of soil borne monomeric phenols with hu-

mic acids. Organic Geochemistry 36, 583-593. (2005)

[45] M.A. Sanchez-Monedero, A. Roig, J. Cegarra, M.P. Bernal, Relationship between water-soluble carbohydrate and phenol fraction and the humification indices of different organic wastes during composting. Bioresource Technology 70, 193-201, (1999)

[46] A. Baddi, J. Cegarra, J. Merlina, G. Revel, J.C. Hafidi, Qualitative and quantitative evolution of polyphenolic compounds during composting of an olive-mill waste-ws mixture. Journal of Hazardous Materials 165, 1119-1123, (2009)

[47] F.J. Stevenson, Humus, Chemistry, Genesis, Composition, Reaction. Wiley Interscience. New York, (1994)

[48] S. Hachicha, J. Cegarra, F. Sellami, R. Hachicha, N. Drira, K. Medhioub, E. Ammar, Elimination of polyphenols toxicity from olive mill wastewaters sludge by its co-composting with sesame bark. Journal of Hazardous Materials 161, 1131-1139, (2009)

[49] G. Gigliotti, P. Proietti, D. Said-Pullicino, L. Nasini, D. Pezzolla, L. Rosati, P.R. Porceddu, Co-composting of olive husk with high moisture contents: organic matter dynamic and compost quality. International Biodeterioration and Biodegradation 67, 8-14, (2012)