TITLE

Influence of the feed pipe position of an industrial scale two-phase decanter on extraction efficiency and chemical-sensory characteristics of virgin olive oil

RUNNING TITLE

Decanter feeding impact on extraction efficiency and olive oil quality

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ABSTRACT

BACKGROUND: Nowadays, olive oil extraction is basically made by means of two-phase decanters, which allow to reduce water consumption and leaching of phenolic compounds. Despite this, most of the working settings derive from studies carried out on three-phase decanters. Hence, aim of the present study has been assessing the influence of two-phase decanter feed pipe position (FP) on the extraction efficiency and chemical-sensory characteristics of virgin olive oil. Three different positions have been considered, at 825 mm (FP1), 610 mm (FP2), and 520 mm (FP3) from the outlet of the oily phase.

RESULTS: Position FP3 allowed the highest oil recovery (up to 10%), the lowest percentage of oil in the olive pomace and, in general, a regular trend in terms of oil extraction efficiency. However, the oily must that came out of the decanter was not completely clean in terms of residual content of solid sediment and water. The feeding position partially affected the profile of antioxidant compounds.

CONCLUSION: In two-phase decanters, loading the olive paste close to the outlet of the oily phase is recommended in order to increase the extraction efficiency without jeopardising the chemical-sensory characteristics of virgin olive oil.

KEYWORDS

Decanter; Olive oil extraction; Virgin olive oil; Extraction efficiency; Quality.

INTRODUCTION

Virgin olive oil production has been deeply studied from the field stage, to the promotion of main product, and including the disposal of the by-products.[1-5] Over the years, due to the discontinuous processing and high management costs, the olive oil extraction system has undergone profound changes: the traditional olive processing by pressure has been replaced by more efficient centrifugation systems based on two-phase and three-phase decanters.[6,7] However, the latter are known to have disadvantages such as: i) high energy and water consumption for the dilution of olive paste; ii) excessive volume of vegetation water, which causes high disposal costs; iii) loss of minor water-soluble constituents of the oils, in particular phenolic substances; iv) variation of organoleptic characteristics of the oils.[8,9]

In addition, Cauteruccio et al. highlighted other critical aspects, due to the thickness of the cloak and to the length and thickness of the auger hollow shaft.[10] The same authors have still found difficulties in modelling a machine such as a three-phase decanter, due to its geometry and the composition of the fluid inside it; in fact, the olive paste, depending on the position along the axis, varies considerably its composition in terms of specific weight and density. On the other hand, already in a previous experimental-theoretical study, some parameters such as solid flow coefficient, drag number, and dynamic productivity coefficient have been considered to design the three-phase decanters, further used by Boncinelli et al.[11,12] This has led to the development of the three-phase water-saving decanter, equipped with auger/drum differential speed control systems, and assisted by automatic control mechanisms.[13] Moreover, the same authors found that in order to produce an additional liquid phase separation effect from the solid matrix, the introduction of barriers near the decanter drainage mouth, the use of variable speed screw conveyor, and the modification of the contour cone profile allowed a wide range of processing conditions, such as: water and oil flow rates, differential speed of the cochlea with respect to the drum, drainage levels of the water and oil.[13] By the proper adjustments of the above parameters, the extraction efficiency was constant in a very wide range of feed rates (1800-2800 kg h^{-1}), higher than the previous decanters, especially at low dilution of the olive paste.[13] Similar results have been reported recently by Squeo et al.[14] In a study of optimization of a three-phase water-

saving decanter it was noted that the extraction efficacy was directly related to the time of paste permanence and inversely to the differential speed (ΔN).[15] Tamborrino et al. investigated, instead, on rheological properties, energy consumption, oil yield, and quality when the calcium carbonate was used during the extraction process.[16]

The two-phase decanter, on the contrary, has been studied mainly by a qualitative point of view.[17,18] In particular, Klen et al. evaluated the content of phenols by comparing different extraction systems; Caponio et al. evaluated the chemical composition of extra virgin olive oil in function of the decanter set-up (two- and three-phase) and the differential speeds between drum and cochlea (ΔN16 and ΔN11).[19,20] Moreover, Giovacchino and co-authors found that by using a decanter capable of working at two- and three-phase, comparable yields were obtained when in the two-phase process the feed rate was reduced to 60-70% of the theoretical value advised; Ayr et al., instead, highlighted the importance of paste preparation in two-phase separation by studying a fluid-dynamic simulation model adaptable to two-phase extraction.[21-23] Finally, a study carried out by Tamborrino et al. using an innovative decanter, able to switch from three- to two-phase processing without interrupting the extraction, allowed a correlation between the flow rate, the oil outlet level, the drum/cochlea ΔN, and the extraction efficiency.[7]

In this framework, the need of a further investigation on the working parameters of the two-phase decanter is highlighted, since many of the technical solutions adopted are currently based on those used in three-phase machines. The purpose of this work was therefore to investigate the influence of the position of the olive paste feed pipe (FP) in a two-phase industrial-scale decanter capable of working at high feed rates, by evaluating the results in terms of extraction efficiency and chemical-sensory characteristics of the virgin olive oil obtained. Then, three different positions have been considered, at 825 mm (FP1), 610 mm (FP2), and 520 mm (FP3) from the outlet of the oily phase.

EXPERIMENTAL

Industrial olive oil extraction plant

The experimental tests were carried out in an industrial olive oil mill (Cooperativa Produttori Olivicoli) located in Bitonto (Apulia, Italy) using a two-phase decanter (REX250 model, Amenduni Nicola S.p.a., Modugno, Italy). In this decanter, olive paste is fed from the opposite side to the conical section (i.e. the "beach" zone), with the possibility to move the feed pipe through the drum section, depending on the ripeness degree of olives and the need to set the two- (oil and pomace) or three-phase (oil, water, and pomace) mode, which is made possible by the simple adjustment of water and oil levels. The internal screw conveyor rotates faster than the decanter drum, and the residence time of the pomace can be adjusted by varying the differential speed (ΔN).

Olive fruits (*Olea europaea* L.) of Coratina cultivar, mechanically harvested in the fifteen last days of November 2016, after leaf-removal, were milled unwashed within 24 h. Two lots of olives were processed in different days, characterized by a maturity index, determined as reported in Squeo et al. equal to 1.07 and 1.39, respectively.[24]

A lot of about 12,000 kg of olives was considered for each trial. Figure 1 shows the flux diagram of olive oil processing. In particular, each olive lot was milled with a hammer-crusher (A60 model, Amenduni Nicola S.p.a., Modugno, Italy) operating at 1,500 rpm, with a processing capacity of 7,000 kg h^{-1} and grid with holes of 6 mm of diameter, then the olive paste was transferred in the malaxer (6V1000 model, Amenduni Nicola S.p.a., Modugno, Italy). After malaxation (90 min at 27±1 °C), the paste was pumped into a two-phase decanter (REX250 model, Amenduni Nicola S.p.A., Modugno, Italy) – operating at 2,800 rpm (bowl) and 2,825 rpm (screw), with a processing capacity of 6,000 kg h^{-1} without dilution with water – in three different feed pipe (FP) positions: at 825 mm (FP1), 610 mm (FP2), and 520 mm (FP3) from the outlet of the oily phase, as shown in Figure 2. Finally, the oily must was cleaned with a vertical centrifuge (A3500 model, Amenduni Nicola S.p.a., Modugno, Italy), operating at 6,400 rpm and 2,000 L h^{-1}. During olive processing, three different samples (every 5 minutes) of oily must (OM), olive pomace (OP), and cleaned oil (O) were collected for each feed pipe position. Moreover, three samples of olive pastes, for each trial, were collected at the end of malaxation step for the viscosity measurements.

Analytical determinations

The viscosity measurements were carried out by a Viscotester VT 550 HAAKE (Thermo Fisher Scientific Inc., Waltham, MA, USA) using 600 mL of olive paste, put into 1,000 mL glass containers and conditioned at same malaxation temperature in a thermostatic bath (27 °C). To interpret the experimental results in terms of viscosity, the acquired torque-speed data and scale readings were converted into shear stress-shear rate relationships using numerical conversion values using the instrument calibration map. The power-law model was used to calculate the apparent viscosity and flow behaviour index from the shear rate using the following Eq (1):

$$\eta_{app} = k\,\gamma^{n-1} \quad (1)$$

where η_{app} is the apparent viscosity, γ is the shear rate (s^{-1}), n is the flow behaviour index (dimensionless), k is the consistency index (Pa s^n). This model is widely used in fluid dynamics analysis when studying biological fluids as the olive paste that is a mixture of three components: olive oil, vegetation water, solid particles. While olive oil and pure water (not vegetation water) are typical Newtonian fluid characterized by a constant viscosity coefficient, olive paste has more complex rheological behaviour. Its viscosity cannot be considered as constant and depends on several parameters.[25] The simplest model that can be used for this fluid is just the power-law model.

The extraction efficiency (EE) was calculated as the ratio between the weight of virgin olive oil (W_{oil}) obtained at the end of the process, and the weight of oil contained in the corresponding olives determined by Soxhlet extraction (W_{olive}). Results of Eq. (2) were expressed as percentage (%).

$$EE = \frac{W_{oil}}{W_{olive}} \times 100 \quad (2)$$

The moisture (g 100 g^{-1}) and total oil (g 100 g^{-1}) content of olives and olive pomaces, as well as the free fatty acids (FFA), peroxide value (PV), and spectrophotometric constants of the extracted oil were determined as described in a previous paper.[26] The moisture content of oils was determined at 103±2 °C, according to the ISO method 662/2016, while the solid impurity

content of the oils was determined after centrifugation at 4,625 × *g* (SL 16R Centrifuge, Thermo Fisher Scientific Inc., Waltham, MA, USA), and the results were expressed as a percentage ratio.[27] The determination of total phenolic compounds by UV spectrophotometry, chlorophylls, carotenoids, and tocopherols was carried out as reported in a previous paper.[16] The determination of the phenolic compounds by HPLC was carried out as described in Caponio et al.[28] For the determination of the volatile compounds, the oil samples (1 ± 0.005 g) were weighed into 20 mL vials, sealed with a screw top aluminium cap and pierceable butyl rubber septa, and submitted to the (SPME/GC-MS) in the conditions reported by Caponio et al.[20] The sensory analysis was performed by a trained panel made of eight judges, experienced in olive oil sensory evaluation in accordance with the Commission Regulation (ECC) No 2568/91.[29]

Statistical analysis

Results were expressed as mean ± standard deviation (SD) of three measurements for the analytical determination. Analysis of variance (ANOVA), followed by Tukey HSD test for multiple comparisons was carried out on the experimental data by means of XLStat software (Addinsoft SARL, New York, NY, USA). Differences were considered significant at $p \leq 0.05$.

RESULTS AND DISCUSSION

Decanter performance in relation to feed pipe position

Figure 3 reports the rheological profiles of the shear stress versus shear rate for each olive paste after 90 min of malaxation. As shown, the apparent viscosity of the samples decreased with the share rate, in accordance to Tamborrino et al., due to the behaviour as pseudoplastic material of the olive paste.[16] The slightly lower values of apparent viscosity of the samples from the second trial could be imputable to higher maturity index of the olives, which causes a higher amount of oil in the olives (data not shown) and an easier breaking of tissues and cells.[30] This allows an increase of the availability of the liquid fraction and, consequently, the separation between the solid and liquid phases within the olive paste and the coalescence of the oil drops.

Table 1 reports for each trial the moisture and oil content of the olive pomace after centrifugation with two-phase decanter, as well as the extraction efficiency. The moisture content of the pomace did not vary significantly in relation to the different feeding position of the olive paste in the decanter, while the residual oil content was significantly lower in FP3 compared to the other two positions. Extraction efficiency was also significantly higher in FP3, reaching the values of 83.24% in the first trial and 84.32% in the second, confirming the better performances of the FP3 position. Considering the results in both the trials, it is highlighted an average increase of extraction efficiency over FP1 and FP2 above 3%. Such a percentage is relevant in the industrial production of virgin olive oil.

Figure 4 reports the moisture and solid content of the oily must withdrawn at the decanter outlet in the second trial. The oily must obtained with the FP3 position had significantly higher moisture content and impurities than the other two samples (FP1 and FP2), which did not show significant differences between them. In particular, more than 5% of moisture and more than 17% solids were observed in FP3 samples, whereas less than 2% moisture and approximately 8% solids were ascertained in FP1 and FP2 samples.

The explanation of such trend could be found in the different resident time experienced by the oily phase in the decanter. In fact, when olive paste is fed in FP3, i.e. the closest position to the oily must outlet, the oily phase has a resident time no long enough to clarify, differently from what happens when the olive paste is fed in a deeper section through the drum, which forces the oily phase to a longer pathway before leaving the decanter (FP1 and FP2). Nonetheless, it is worth to note that no significant difference in content of moisture and impurities was further detected after the oil finishing by means of the vertical centrifuge (data not shown), that is an usual step in the industrial production of virgin olive oil by means of decanters.

In the light of the aforementioned results it is possible to conclude that in two-phase decanter is recommended to load the olive paste close to the outlet of the oily phase. Moreover, it should be considered that in the two-phase decanter, in which the feeding is carried out on the opposite side from the conical end, the feed pipe does not reach such lengths able to reach the best position for the introduction into the decanter (Fig. 2); as a consequence, these machines do not

require any vibrational check-ups when working at maximum rotation speed. From a constructive point of view, the vibration of the auger shaft is essentially due to the mass of the reducer to which it is attached and to the auger mass, so it can vibrate depending on the length and thickness. On the other hand, the auger shaft is subjected to several design constraints: the outer diameter can not be increased because it is constrained into the inner diameter of the bearings and, in most cases, increasing the bearing diameter would cause a significant increase of the costs.[10] In the two-phase decanters, in which the feeding occur at the conical side, the possibility of varying the relative rotation speed between the auger and the drum (ΔN) is particularly important, both for flexural equilibrium and for the success of the separation process. Indeed, ΔN is one of the parameters which, acting on the olive paste resident time, can effectively improve the separation efficiency without needing excessive rotational speeds, if appropriately adjusted. In this perspective, for the two-phase process, the position where to feed the olive paste should be preferably on the opposite side of the cone, allowing to move the injection tube into more internal drum sections depending on the physical characteristics of olive paste and according to the possible need to set the machine in the three-phase mode.

Virgin olive oil quality

Table 2 shows the results of the chemical and sensory analyses performed on the oils. All samples exhibited acidity, peroxide value and spectrophotometric constant values within the limits set by the rules for the classification of oil as extra virgin, indicating the good quality of the olives used.[31] In fact, the acidity and peroxide values did not exceed the value of 0.4% and 8 mEq O_2 kg^{-1}, respectively. Slightly higher K_{270} values were observed for the oils of the second trial. These latter samples, on the other hand, showed higher average values of lipophilic (carotenoids, tocopherols) and hydrophilic (phenolic compounds) antioxidants, as well as more marked pungent sensory notes, compared to those of first trial.

The feeding position did not cause substantial changes in the chemical profile, as well as in the sensorial characteristics of the oils. Significantly influenced, in fact, were only the lipophilic antioxidant compounds and, in one of the trials, the pungent note and the content of

chlorophylls. Differently, the phenolic content of the oils was not significantly influenced by machine setting. In any case, although without statistical significance, in both the trials FP3 samples approximately showed a 10% lower phenolic content than FP1 and FP2. This result could be explained by considering the composition of the oily must. In fact, as shown in Figure 4, the oily must obtained from FP3 position had a significantly higher content of water and solids. Given the great affinity of the phenolic compounds for the aqueous phase it can be thought that they are preferably distributed in the latter and therefore lost with it in the subsequent processing step of oil finishing by vertical centrifuges.

Carotenoids are a group of tetraterpenoids consisting of isoprene units, and are important liposoluble antioxidants present in oils and fats.[32] FP1 feeding caused a significant reduction in carotenoids content respect to both FP2 and FP3 in the second trial, and to FP2 in the first trial. This result can be explained considering the low polarity of these compounds and the behaviour of the pomace in the decanter. In fact, FP1 position caused a quick discharge of the pomace from the decanter and therefore made the pomace retain a significantly higher amount of oil compared to other feeding positions (Table 1). Thus, given the carotenoids affinity for the oily phase, it can be supposed that their dissolution in the pomace was higher in the FP1 samples than in the others.

A similar trend was found for α-tocopherol and, consequently, for the total tocopherols, representing the former about 90% of total tocopherols in virgin olive oils.[33] In particular, the FP2 oil had significantly higher content of tocopherols than FP1, in both the trials. This may be due to the chemical characteristics of these compounds which, similarly to carotenoids, have hydrophobic character. However, unexpectedly, a decrease in the tocopherols content was also observed in the FP3 oils compared to the FP2 samples.

Regarding the sensory characteristics of the oils, there was a significant influence of the decanter feed pipe position on the pungent note in the case of the first trial, with significantly higher values for the FP2 samples, according to the highest total phenolic content observed in the same samples. The chlorophyll content showed a significant difference only in the second trail for FP1 samples, which had a higher content than the others.

Table 3 shows the content of the individual phenolic compounds determined by HPLC. The oils from the second trial had a higher average content of phenolic compounds compared to the first trial. Overall, the feed pipe position of the olive paste in the decanter has weakly affected the phenolic profile. Consistently with total phenols (Table 2), FP3 position caused a reduction of the phenolic content, significant in the first trial. This result was a consequence of the significant decrease in some of the derivative forms of secoiridoids, in particular the dialdehydic form of the elenolic acid linked to the hydroxytyrosol (3,4-DHPEA-EDA) and tyrosol (*p*-HPEA-EDA), known to be among the most abundant in virgin olive oils.[34] In particular, the dialdehydic form of elenolic acid linked to the tyrosol (p-HPEA-EDA), also known as oleocanthal, has long been recognized as the main responsible for the pungency of virgin olive oils and associated with anti-inflammatory activity similar to that of ibuprofen. [35] Nevertheless, in our study no straight correlation has been observed between oleocanthal and samples pungent note (Table 2). In the case of the second trail, the only significant differences involved vanillic acid and apigenin. However, a trend similar to that found for the first trial was observed for 3,4-DHPEA-EDA, but not for the oleocanthal.

Table 4 shows the volatile compounds found in oils. In both the trails, *trans*-2-hexenal was the most abundant compound, as widely documented in literature.[28,36,37] The feed pipe position did not lead to significant changes in the volatile profile and only a few significant differences were observed. Also for volatiles, the behaviour was different in the tests suggesting a possible influence of the ripening degree of olives.

Considering the first trial, loading the olives paste in FP1 resulted in a significant decrease in *trans*,*trans*-2,4-hexadienal, 1-penten-3-one and a significant increase in 1-hexanol, the latter only with respect to FP2 test. Further, the FP2 test showed significantly higher values of ethyl acetate, probably linked to the particular batch of olives used, although derived from a homogeneous batch, and 1-penten-3-one. The FP3 test had significantly lower values of 2-methyl-4-pentenal, 1-penten-3-one and limonene respect to the others. In the second trial, significant decreases of ethanol, *trans*-2-hexen-1-ol and ethyl acetate were observed in FP1, while only *trans*-3-hexen-1-ol acetate in FP2. Finally, FP3 oils had significantly higher content

of ethanol and *trans*-3-hexen-1-ol acetate. Tentatively, the explanation of what observed might be linked to the polarity of the volatile compounds, similarly to what observed for phenolics. Indeed, more polar groups such as esters and aldehydes could be more likely found in FP3 oils, richer in water at exit from the decanter, than the other samples. However, such behaviour was not observed in both the trials and it was more evident and statistically significant only in the case of trial II.

CONCLUSIONS

Considering the results about the performances of the two-phase decanter, with the olives used in this experimental study, the position of the feed pipe tube closer to the oil discharge section (FP3) allowed to reach the highest oil recovery and a regular trend in terms of extraction efficiency. On the other hand, the extracted oil was found to contain more sediment and water. The farthest positions from the liquid exit are the worst considering the extraction efficiency, but make it possible to have cleaner oil, although the cleaning of the oily must, carried out in the vertical separator, is usually included in any olive processing plant.

Interestingly, our findings highlighted as the different decanter feeding position is also able to influence the balance of lipophilic/hydrophilic antioxidants in the oils. In fact, when the olive paste feeding takes place nearest to the solid discharge (FP1), the resulting oil is richer in phenols and contains less tocopherols and carotenoids than the opposite FP3 position.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interests regarding the publication of this paper. Lucio Brunetti, Pasquale Catalano, and Biagio Bianchi edited the “Decanter performance in relation to feed pipe position” section; while Francesco Caponio, Giacomo Squeo, Antonella Pasqualone, Carmine Summo, and Vito M. Paradiso edited the “Virgin olive oil quality” section.

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FIGURE CAPTION

Figure 1. Experimental plan and sampling points.

Figure 2. Different positions of the decanter feed pipe, at 825 mm, 610 mm, and 520 mm from the outlet of the oily phase.

Figure 3. Shear stress versus shear rate of three olive pastes (P1, P2, P3) collected in two different olive processing trials. First trial (I-T) corresponded to olives having maturity index lower than those of second trial (II-T).

Figure 4. Moisture and insoluble impurity content of the oily must obtained in an olive processing trial with olives having a maturity index of 1.39 (second trial) (n=3).Three different decanter feed pipe (FP) positions were considered, positioned at 825 mm (FP1), 610 mm (FP2), and 520 mm (FP3) from the outlet of the oily phase.

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Table 1. Pomace moisture, pomace oil content and oil extraction efficiency (n=3) determined in two different olive processing trials. First trial corresponded to olives having maturity index lower than those of second trial. Three different decanter feed pipe (FP) positions were considered, at 825 mm (FP1), 610 mm (FP2), and 520 mm (FP3) from the outlet of the oily phase.

Trial	Pomace moisture (%)	Pomace oil content (% d.m.)	Oil extraction efficiency (%)
I trial			
FP1	62.11±0.89 a	8.89±0.25 a	75.32±0.40 c
FP2	62.78±0.65 a	8.58±0.10 ab	77.71±0.21 b
FP3	62.14±1.55 a	8.17±0.32 b	83.24±1.36 a
II trial			
FP1	63.42±1.16 a	8.42±0.47 a	81.60±1.26 b
FP2	65.02±3.03 a	8.62±0.57 a	82.71±1.48 ab
FP3	63.56±1.35 a	7.60±0.12 b	84.32±0.55 a

Different letters on the same row for the same trial indicate significant differences ($p \leq 0.05$) according to one way ANOVA followed by Tukey's HSD test.

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Table 2. Mean values, standard deviations and results of the one way ANOVA followed by Tukey's HSD test of the chemical and sensory analyses performed on the oils (n=3) obtained in two different olive processing trials. First trial (I) corresponded to olives having maturity index lower than those of second trial (II). Three different decanter feed pipe (FP) positions were considered, at 825 mm (FP1), 610 mm (FP2), and 520 mm (FP3) from the outlet of the oily phase.

Trial	**I**			**II**		
Sample	**FP1**	**FP2**	**FP3**	**FP1**	**FP2**	**FP3**
FFA (g 100g^{-1} oleic acid)	0.37±0.00 a	0.37±0.00 a	0.37±0.00 a	0.37±0.00 a	0.37±0.00 a	0.37±0.00 a
PV (mEq O_2 kg^{-1})	8.0±0.8 a	7.7±1.0 a	7.8±0.5 a	6.7±0.9 a	6.4±0.7 a	6.6±1.1 a
K_{232}	1.70±0.02 a	1.71±0.04 a	1.69±0.04 a	1.67±0.03 a	1.66±0.03 a	1.73±0.12 a
K_{270}	0.17±0.03 a	0.17±0.05 a	0.18±0.04 a	0.19±0.02 a	0.20±0.03 a	0.22±0.08 a
TPC (mg kg^{-1})	356±28 a	387±41 a	314±26 a	480±23 a	460±27 a	433±7 a
Chlorophylls (mg kg^{-1})	15.72±0.81 a	16.04±0.03 a	16.41±0.14 a	15.56±1.45 a	13.30±0.24 ab	13.09±0.76 b
Carotenoids (mg kg^{-1})	12.34±1.33 b	14.22±1.68 ab	16.50±0.57 a	12.88±2.32 b	18.54±2.43 a	18.03±0.88 a
β+γ-Tocoferols (mg kg^{-1})	3.71±0.40 a	4.41±0.39 a	4.37±0.15 a	5.28±0.03 a	5.75±0.23 a	5.24±0.51 a
α-Tocoferol (mg kg^{-1})	159.37±1.37 b	163.93±1.58 a	162.07±1.79 ab	170.16±0.99 ab	172.27±0.07 a	169.25±1.14 b
Tocoferols (mg kg^{-1})	163.08±1.75 b	168.35±1.95 a	166.44±1.91 ab	175.44±0.96 b	178.02±0.23 a	174.49±1.15 b
Fruity*	3.5±0.7 a	5.0±0.7 a	4.3±0.5 a	3.6±0.5 a	3.8±0.6 a	3.5±0.7 a
Bitter*	2.2±0.3 a	2.6±0.7 a	1.7±0.5 a	2.5±0.2 a	2.5±0.4 a	2.1±0.2 a
Pungent*	2.3±0.1 a	3.2±0.6 a	2.2±0.6 a	3.3±0.3 a	2.4±0.1 a	2.8±0.4 a

FFA, free fatty acids; PV, peroxide value; K_{232}, specific absorption at 232 nm; K_{270}, specific absorption at 270 nm; TPC, total phenolic content.
*Median ± robust standard deviation (Regulation ECC No 2568/91). Statistical significance was determined by Kruskal-Wallis test ($p \leq 0.05$).
Different letters on the same row for the same trial indicate significant differences ($p \leq 0.05$).

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Table 3. HPLC phenolic profile (mg kg^{-1} ± sd) of the oils obtained in two different olive processing trials (*n*=3). First trial (I) corresponded to olives having maturity index lower than those of second trial (II). Three different decanter feed pipe (FP) positions were considered, at 825 mm (FP1), 610 mm (FP2), and 520 mm (FP3) from the outlet of the oily phase.

Trial	**I**			**II**		
Sample	**FP1**	**FP2**	**FP3**	**FP1**	**FP2**	**FP3**
Hydroxytyrosol	0.28±0.02 a	0.28±0.03 a	0.25±0.05 a	0.54±0.10 a	0.58±0.10 a	0.56±0.04 a
Tyrosol	0.47±0.02 a	0.46±0.04 a	0.47±0.01 a	0.66±0.09 a	0.75±0.05 a	0.76±0.02 a
Vanillic acid	0.20±0.06 a	0.19±0.04 a	0.22±0.05 a	0.22±0.01 ab	0.20±0.02 b	0.25±0.01 a
Syringic acid	0.35±0.04 a	0.37±0.05 a	0.37±0.03 a	0.32±0.07 a	0.32±0.09 a	0.33±0.08 a
3,4-DHPEA-EDA	28.26±0.68 a	28.13±1.33 a	21.86±0.74 b	28.47±4.47 a	24.89±4.71 a	23.27±1.31 a
Oleuropein	1.43±0.27 a	1.34±0.20 a	1.03±0.05 a	2.73±0.29 a	2.52±0.87 a	2.18±0.15 a
p-HPEA-EDA	25.35±0.26 ab	25.70±0.85 a	23.89±0.70 b	25.49±1.15 a	26.51±0.27 a	26.31±0.48 a
(+)-Pinoresinol	10.36±0.23 a	10.90±0.22 a	10.05±0.54 a	12.26±0.54 a	12.44±0.15 a	12.09±0.20 a
1-Acetoxypinoresinol	0.86±0.03 a	1.02±0.05 a	1.00±0.22 a	2.38±0.16 a	2.61±0.19 a	2.28±0.11 a
Cinnamic acid	0.43±0.24 b	0.91±0.10 a	1.14±0.21 a	1.94±0.43 a	2.32±0.36 a	2.42±0.13 a
3,4-DHPEA-EA	4.75±0.25 a	4.78±0.10 a	4.43±0.20 a	4.43±0.41 a	4.98±0.16 a	4.60±0.16 a
Luteolin	3.65±0.46 a	3.95±0.43 a	3.24±0.26 a	4.14±0.37 a	4.38±0.60 a	4.50±0.36 a
p-HPEA-EA	3.54±0.17 a	3.70±0.26 a	3.65±0.18 a	3.30±0.06 a	3.55±0.31 a	3.31±0.17 a
Apigenin	6.07±0.06 a	6.41±0.35 a	6.02±0.17 a	4.13±0.05 b	4.36±0.03 a	4.19±0.05 b
Total	**86.00±0.18 a**	**88.15±3.49 a**	**77.61±2.10 b**	**91.01±7.89 a**	**90.39±6.14 a**	**87.05±2.43 a**

3,4-DHPEA-EDA, dialdehydic form of elenolic acid linked to hydroxytyrosol; *p*-HPEA-EDA, dialdehydic form of elenolic acid linked to tyrosol; 3,4-DHPEA-EA, oleuropein aglycon; *p*-HPEA-EA, ligstroside aglycon.

Different letters on the same row for the same trial indicate significant differences ($p \leq 0.05$) according to one way ANOVA followed by Tukey's HSD test.

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Table 4. Profile of volatile compounds (mg kg^{-1} ± sd) of the oils obtained in two different olive processing trials (n=3). First trial (I) corresponded to olives having maturity index lower than those of second trial (II). Three different decanter feed pipe (FP) positions were considered, at 825 mm (FP1), 610 mm (FP2), and 520 mm (FP3) from the outlet of the oily phase.

	Trial	**I**			**II**		
	Sample	**FP1**	**FP2**	**FP3**	**FP1**	**FP2**	**FP3**
Aldehydes	Hexanal	8.34±0.93 a	7.88±0.91 a	7.67±0.64 a	7.57±1.48 a	8.10±0.99 a	10.21±0.48 a
	cis-3-Hexenal	5.30±0.55 a	4.81±0.81 a	5.07±1.24 a	4.78±1.50 a	6.58±0.68 a	5.41±0.16 a
	trans-2-Hexenal	232.90±25.53 a	222.80±32.64 a	225.15±21.93 a	177.08±25.01 a	195.70±17.34 a	217.63±5.37 a
	3-Metilbutanal	0.28±0.06 a	0.35±0.05 a	0.24±0.03 a	0.03±0.03 b	0.12±0.01 a	0.09±0.00 a
	trans-2-Pentenal	1.33±0.13 a	1.17±0.18 a	1.20±0.29 a	1.20±0.29 a	1.38±0.16 a	1.63±0.20 a
	Nonanal	0.84±0.12 a	0.94±0.15 a	0.62±0.20 a	0.28±0.10 a	0.25±0.04 a	0.28±0.10 a
	trans,trans-2.4-Hexadienal	2.70±0.46 b	4.92±0.93 a	4.34±0.40 a	3.39±1.47 a	4.82±0.45 a	2.94±0.31 a
	2-Metil-4-pentenal	6.80±0.78 a	6.23±0.81 a	0.65±0.09 b	5.98±1.70 a	6.60±1.05 a	7.07±0.36 a
Alcohols	Ethanol	1.68±0.60 a	1.61±0.24 a	1.01±0.21 a	1.31±0.48 b	1.79±0.47 ab	2.97±0.58 a
	trans-2-Hexen-1-ol	1.66±0.29 a	1.65±0.25 a	2.02±0.32 a	0.84±0.41 b	2.40±0.94 a	3.41±0.16 a
	1-Hexanol	1.85±0.32 a	1.05±0.18 b	1.37±0.16 ab	2.12±0.51 a	1.77±0.71 a	1.65±0.68 a
Esters	*trans*-3-Hexen-1-ol acetate	4.60±0.50 a	4.98±0.84 a	4.31±1.26 a	4.21±0.37 ab	3.56±0.52 b	5.01±0.68 a
	Ethyl acetate	0.68±0.04 b	1.11±0.16 a	0.67±0.16 b	0.45±0.06 b	0.71±0.03 a	0.72±0.08 a
	cis-3-Hexenil acetate	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00 a	0.13±0.23 a	0.00±0.00 a
	Metil acetate	0.06±0.11 a	0.19±0.17 a	0.20±0.06 a	0.18±0.07 a	0.20±0.08 a	0.24±0.01 a
Ketones	1-Penten-3-one	9.99±0.61 b	12.03±0.82 a	7.24±0.56 c	8.88±2.83 a	9.96±1.80 a	12.57±0.99 a
	3-Pentanone	1.34±0.14 a	1.48±0.26 a	1.14±0.22 a	1.01±0.44 a	1.26±0.23 a	1.50±0.17 a
Acids	Acetic acid	1.04±0.57 a	0.73±0.07 a	1.95±1.94 a	0.00±0.00 a	0.00±0.00 a	0.00±0.00 a
Others	Octane	0.82±0.14 a	1.08±0.19 a	1.14±0.53 a	0.56±0.09 a	0.62±0.15 a	0.59±0.07 a
	Limonene	0.53±0.03 a	0.56±0.05 a	0.40±0.06 b	0.56±0.16 a	0.69±0.11 a	0.80±0.13 a
Total		**282.75±28.97 a**	**275.57±38.81 a**	**266.38±24.49 a**	**220.43±25.73 b**	**246.63±21.12 ab**	**274.72±7.77 a**

Different letters on the same row for the same trial indicate significant differences ($p \leq 0.05$) according to one way ANOVA followed by Tukey's HSD test.

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