Research Article

Specification of a new de-stoner machine: evaluation of machining effects on olive paste's rheology and olive oil yield and quality

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Abstract

BACKGROUND: An industrial prototype of a partial de-stoner machine was specified, built and implemented in an industrial olive oil extraction plant. The partial de-stoner machine was compared to the traditional mechanical crusher to assess its quantitative and qualitative performance. The extraction efficiency of the olive oil extraction plant, olive oil quality, sensory evaluation and rheological aspects were investigated.

RESULTS: The results indicate that by using the partial de-stoner machine the extraction plant did not show statistical differences with respect to the traditional mechanical crushing. Moreover, the partial de-stoner machine allowed recovery of 60% of olive pits and the oils obtained were characterised by more marked green fruitiness, flavour and aroma than the oils produced using the traditional processing systems.

CONCLUSION: The partial de-stoner machine removes the limitations of the traditional total de-stoner machine, opening new frontiers for the recovery of pits to be used as biomass. Moreover, the partial de-stoner machine permitted a significant reduction in the viscosity of the olive paste.
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Keywords: de-stoner machine; rheology; olive paste; olive oil

INTRODUCTION

Extraction operations are the most important factors affecting quality and bioactivity level of virgin olive oil (VOO). All steps of the olive oil extraction influence its quality and yield. This awareness has led in the last 30 years towards a continuous improvement of plants and olive oil process, which had as the goal the high quality of the extra virgin olive oil, high extraction efficiency of the plants and safer processes and equipment. Technological innovations to produce high quality and to improve the extraction yield were implemented according to the literature.[1−17] Regarding the milling operation, the traditional stone mill was replaced by a mechanical crusher, mainly a disc and hammer crusher and the effect of the different crushing system on the quality, yield and degree of stone and oil drops fragmentation was studied.[18−21] In early 2000, a new concept of milling operation was developed: the olive pulp processing excluded the kernel, that is, the woody portion of the fruit.[22] The proposed technology is a useful alternative operation for olive oil production, which involves olive de-stoning before oil extraction using a de-stoner machine. The de-stoner machine removes the entire stone from olives before their malaxation. According to some authors a problem occurring in olive oil extraction would be the high level of endogenous oxido-reductase enzymes, in particular peroxidase, present in the woody stone kernel, which could enhance the risk of oil oxidation. Thus, removal of stones before malaxation partially inhibits peroxidase activity in olive paste and consequently a reduction of the enzymatic degradation of the hydrophilic phenols can occur.

The de-stoning improves the phenol concentration in oil and consequently its oxidative stability, as well as improves the sensorial properties and the volatiles compounds;[23−26] a negative effect on pigment transfer (both chlorophylls and carotenoids) from fruits to oil was observed by some authors.[27,28] Using the de-stoner machine avoids the mechanical and thermal stress of olive paste during the milling operation, increases the amount of olives processed per hour (the increment corresponds to the percentage of stones with respect to the entire olive fruit), and changes the rheological characteristics of olive paste as a result of its increased percentage of moisture.[23]

In a previous work we reported that the use of this technology leads to a decrease of yield and decanter extraction efficiency.[22] The first reason for this weakness is the absence of stone fragments, which makes the malaxation less efficient. In fact, the angular and sharp stone fragments contribute to breaking the residual uncrushed olive pulp cells during malaxation that otherwise would be lost in the waste water or husk. The second reason

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is that the absence of the stone fragments reduces the draining effect of the liquid phase in the decanter during the centrifugation, which consequently reduces its efficiency and the extraction yield. These negative aspects related to the lack of these actions of the stone fragments in olive pastes could partly be solved by increasing the malaxation time and improving the decanter setting, i.e. reducing the mass flow rate.

Despite the positive aspects, also linked to the stones' recovery, these negative aspects have, however, limited the spread of the total de-stoner machine, which achieves a total removal of the olive stones.

In recent years, however, the growing market demand for olive stone fragments (OSFs) to be used for energy purposes, has led an Italian machinery company, with the author's support, to design and build a new de-stoner machine: the partial de-stoner machine (PDM).

The partial de-stoner machine involved in this research does not remove the stone in full, in contrast to the total de-stoner machine used in all the previous studies, but removes only a variable percentage of stone fragments. This is achieved by means of a mechanical solution that allows crushing of the olives and subsequently the separation of a desired quantity of fragmented stones. Thus, if an amount of about 50% of OSF is removed, the remaining 50% of stone fragments with all the pulp continued in the process. Therefore, the olive oil obtained is not classified as 'de-stoned oil' but 'partial de-stoned oil'.

As with all new ideas, the concept of innovation requires extensive investigation, testing and development. This paper analyses a new de-stoner machine as a case study of the technological changes associated with the proposal innovation.

The aim of this study was to investigate the machining effects of the innovative partial de-stoned machine on rheological aspects of the olive paste, on olive oil quality and on the plant efficiency by processing *Coratina* (*Olea europaea* L.) olives. The experiments were carried out comparing the partial de stoner machine with a hammer crusher machine (Control) in an industrial plant.

The paper includes research design, procedures, quantitative and qualitative analyses for furthering understanding of the role played by and consequences of this new de-stoner machine included in the olive oil extraction plants.

MATERIALS AND METHODS

Olives and experimental plant

Coratina olives were mechanical harvested near Foggia, Puglia region, south Italy, during the crop season 2014–2015.

The olive maturity index (MI) was determined according to the method proposed by the International Olive Oil Council,[29] based on the skin colour evaluation. The MI was 1.4. Olives was milled in an industrial extraction plant constituted by a leaf removing machine, washing machine, hammer crusher (mod. Hammer Mill Crusher; Alfa Laval Corporate AB, Lund, Sweden) with grid hole of 7 mm, or an innovative PDM (mod. Moliden; Pietro Leone e Figli s.n.c., Foggia, Italy), group of six open malaxer, a 3-phase decanter (mod. NX X32; Alfa Laval Corporate AB) and two vertical plate centrifuges (mod. UVPX 507; Alfa Laval Corporate AB).

Each trial was replicated three times using a homogenous olive batch divided in three sub-batches of 700 kg each.

Process parameters were: (1) malaxation time = 40 min; (2) malaxation temperature = 27 °C; (3) plant mass flow rate = 3000 kg h^{-1}; (4) water added to the decanter = 15% of the
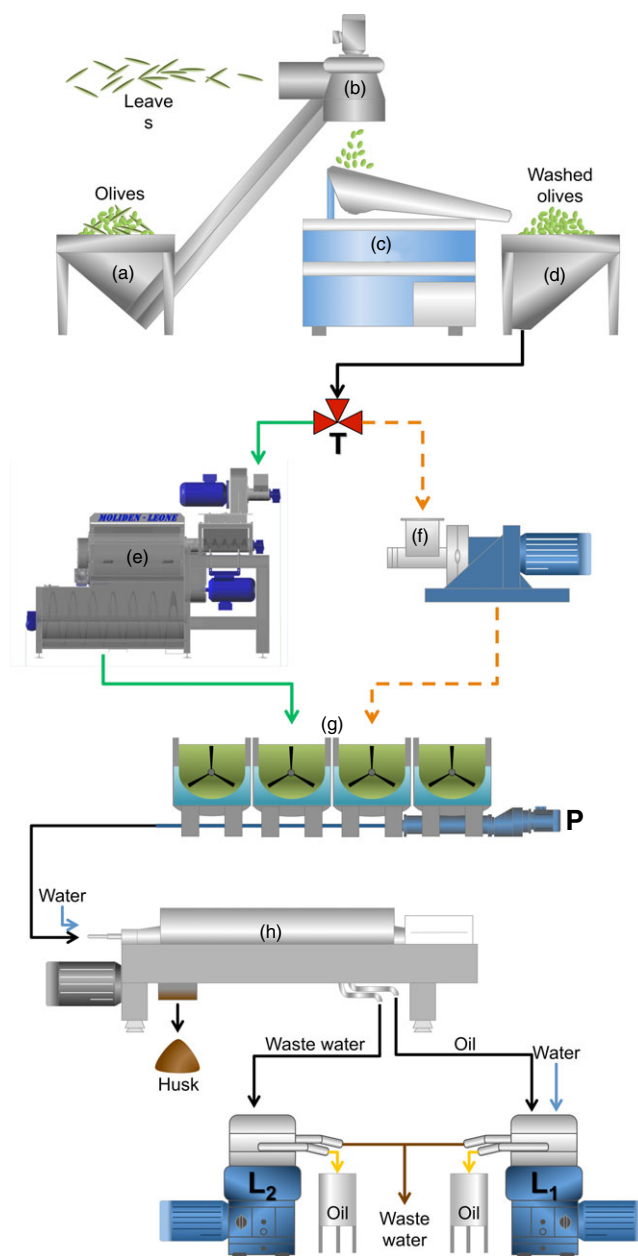
Figure 1. Layout of industrial olive oil extraction plant and process: (A) loading hopper; (B) defoliator; (C) washing machine; (D) hopper; (T) three-way valve; (E) partial de-stoner machine; (F) hammer crusher; (G) malaxer machines; (H) solid/liquid horizontal centrifugal decanter; (L) liquid–liquid vertical centrifuges; (P) Cavity Pump.

processed olives' weight. Figure 1 shows the layout of industrial olive oil extraction plant and process.

Specification of partial de-stoner machine

The project parameters used for the partial de-stoner development are listed below:

- Stainless steel AISI-316 used for all parts in contact with olive paste
- Variable paste flow rate until 6000 kg h^{-1} [olives]
- Modulation of discharged pits' quantity, from 0 (traditional configuration) to 100% (total de-stoning configuration)

Figure 2. Partial de-stoner machine: (A) chassis; (B) mechanical crusher; (C) de-stoner section; (D) cochlea conveyor for pits extraction; (E) malaxing section; (F) olive feeding section.

- Pool for temporary containment of partial de-stoned olive paste.

Figure 2 shows the PDM. The chassis (A) is constructed in welded stainless-steel sections. A mechanical crusher (B) constitutes the crushing section. A horizontal bowl made in perforated plate, having inspection panels on its top, constitutes the de-stoner section (C). The de-stoning shaft is mounted in the inner bowl through specific rolls, and moved by an electric motor through mechanical transmission. The de-stoner is included in a couple of safety carters. A cochlea conveyor moved by a motor-reducer, allows extraction of the pits from the de-stoner section (D).

A hopper is placed between the crushing and de-stoning sections in order to recover the olive paste. The paste is transferred in the hopper by a cochlea, moved by a motor-reducer.

The malaxing basin (E) is equipped by a shaft, moved by a motor-reducer, which has the scope to temporarily contain the partially de-stoned olive paste, until it is sent to the malaxer machines.

The olives feed in continuous mode, and pass into the crushing machine through a cochlea from point F. The crusher lightly breaks the olive pulp and stones. Then, the paste obtained passes into the de-stoning section. The olive paste is further broken by impacting the shaft's blades and rubbing the perforated plate. Then broken olive paste and broken stones having dimensions smaller than plate holes, are removed from the bowl. The remaining, largest part of the stones, are held in the bowl and successively discharged. Finally, the partially de-stoned olive paste is conveyed in the malaxing pool.

During the tests, about 60% of stone fragments were extracted. Samples were collected according to the following schedule:

- Before every test, olives were sampled and stored at 4.0 °C in plastic containers.
- After the centrifugal separation in a vertical plate centrifuge, oil was sampled and stored at 4.0 °C in dark glass bottles.

Rheological measurements
The olive paste samples obtained using the two different crushing machines were subjected to rheological analysis through a

Brookfield rotational remoter, model DV2-HBT (Brookfield Engineering Laboratories, Inc., Stoughton, MA, USA) equipped with interchangeable disc spindles, 2–7 (model RV/HA/HB; Brookfield DVII + Brookfield Engineering Laboratories). Viscosity measurements were carried using 600 mL of olive paste, loaded into 1000-mL glass containers conditioned at 27 °C in a thermostatic bath. The apparent viscosity of each sample was recorded at 10 rotational speeds ranging from 0.5 to 100 rpm, using the RV/HA/HB-4 spindle. To interpret the experimental results in terms of viscosity, the torque–speed data and scale readings were converted into shear stress–shear rate relationships using numerical conversion values. An empirical power-law model was used to calculate the apparent viscosity and flow behaviour index from the shear rate using the equation $\eta_{app} = k\gamma^{(n-1)}$, 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 ($Pa\ s^n$). Three replicate trials were performed for each sample.

Quantitative index determinations
During the comparative tests the yield (Y) was measured, olives and olive oil was sampled in order to determine the extraction efficiency (EE) and, finally, the quality of the oil obtained from whole and partially de-stoned olives was determined.

To determine the amount of stone recovered from the machine, during each experimental test all the stone output from the machines has been stored in a bin and subsequently weighed.

To determinate the percentage of stone in the olives, a representative sample of olives (200 units) was manually de-stoned. Subsequently, the stones was cleaned and weighed.

Qualitative index determinations
Free fatty acids, peroxide index and ultra-violet light absorption K232 and K270 were determined by the methods reported in Regulation EEC/2568/91 of the European Union.

Total phenolic content
The phenols were recovered from the oils using a liquid–liquid extraction with methanol, following the procedure reported by Gambacorta et al.[30] Phenolic extract (100 μL) were pipetted in a 10 mL test tube, mixed with 100 μL 2 mol L^{-1} Folin–Ciocalteu reagent and after 4 min, with 800 μL 5% Na_2CO_3. The mixture was then heated in a 40 °C water bath for 20 min and the total phenol content was determined colorimetrically at 750 nm. The standard curve was prepared using diluted solutions of gallic acid in methanol/water (70:30, v/v), using the same procedure described for the phenolic extracts. The total phenolic content was expressed as gallic acid equivalents (mg kg^{-1}).

Analyses of volatile compounds
Extraction
For each treatment replicate, 40.0 g of oil was added with 0.50 mL of 2-methyl-1-pentanol as internal standard (IS), obtaining a concentration of 10.3 mg kg^{-1}. Three grams of sample of the spiked oil were introduced into a 10 mL headspace vial fitted with a Teflon-lined septum sealed with an aluminium seal and analysed. The volatile compounds were extracted by exposing the solid-phase microextraction (SPME) fibre (PDMS/DVB, 50/30 μm, 20 mm long) for 30 min in the sample headspace kept in a 40 °C water bath, and subsequently inserted into the injection port of the gas chromatography–mass spectrometry (GC/MS) system. The

fibre was conditioned for 20 min, before the exposure to the sample head-space, by placing the fibre in the GC injector under constant flow of helium at a temperature of 210 °C.

Identification by gas chromatography – mass spectrometry

A 6890 N series gas chromatograph (Agilent Technologies Inc., Santa Clara, CA, USA) with an Agilent 5975C mass selective detector (MSD) and equipped with a DB-Wax capillary column (60 m × 0.25 mm I.D, 0.25 μm film thickness; J&W Scientific Inc., Folsom, CA, USA) was used. Helium was used as carrier gas at a flow rate of 1.0 mL min^{-1}. Oven temperature was set at 40 °C for 4 min, followed by a temperature gradient of 3 °C min^{-1} to 140 °C, with a final post-run of 10 min at 200 °C.

The mass spectrometer operated in the electron impact mode (ionisation energy, 70 eV) using a mass range of *m/z* 30 – 400 amu. The identification of compounds was performed comparing the retention times with those of standard compounds, when available, and mass spectra with those of the data system library (NIST011, *P* > 90%). For quantitative analysis purposes, the method error was minimised by using internal standard peak area normalisation. Quantification of volatile compounds from olive oil was achieved by multiplying the ratio of analyte peak area to IS peak area (mean value, *n* = 3) by the IS concentration, expressed as mg internal standard equivalents kg^{-1} oil. The associated standard deviation was determined by means of error propagation calculation taking into account the estimated error due to the IS-spiked oil preparation and the standard deviation obtained from replicates for each compound.

All analyses have been made in triplicate.

Sensory analysis
Sensory analysis was performed according to the EU Regulation 1989/2003 (2003), in a sensory room equipped with boots according to ISO standard 8589.[31]

Statistical analysis
Averages and standard deviations calculation, and ANOVA (using Tukey's HSD), calculated with a 95% confidence interval) were performed using the MATLAB statistics toolbox (The MathWorks, Inc., Natick, MA, USA).

In particular, for each trial (HC and PDM), three items of analytical data were collected for each of three replicas. The three analytical data were meant obtaining one data for each trial (HC and PDM).

RESULTS AND DISCUSSION
Rheological characteristics of olive pastes
The different rheological characteristics of the two of olive paste's type are shown in Fig. 3. The characteristics of the shear stress/shear rate relationship were a downward concavity, denoting the pseudo-plastic characteristic of both olive pastes considered. The apparent viscosity was determined applying the power law model and plotted in log – log scale (Fig. 4), to better compare the behaviour of HC and PDM pastes. PDM paste shows lower values of apparent viscosity than HC paste, because the higher adherence due to the less quantity of stone respect to HC paste. The apparent viscosities were statistically different. These results could be associated with the absence of an olive stone fraction.

Viscosity is an important process parameter of the olive oil's extraction cycle. It influences the liquid – solid separation in
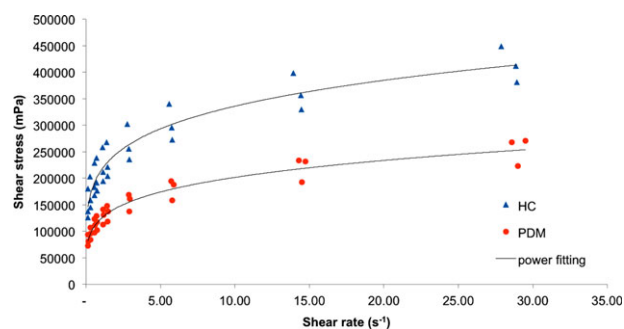

Figure 3. Effect of shear rate on shear stress, for the two trials (HC and PDM).
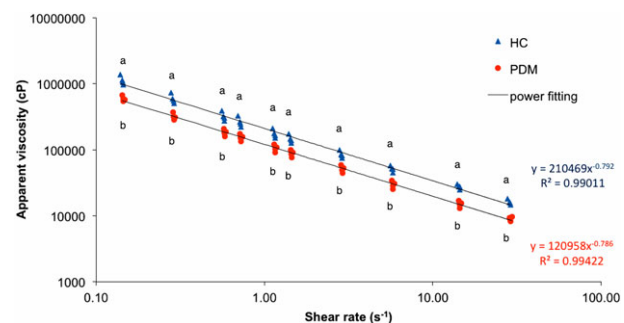

Figure 4. Effect of shear rate on apparent viscosity, plotted in log – log scale, for the two trials (HC and PDM). Different letters denote significant differences (ANOVA and HSD test, *P* < 0.05).

Table 1. Quantitative parameters

Test	Yield (% wt/wt)	EE (% wt/wt)	Stone recovered (% dried basis)
HC	14.9 ± 0.4^a	83.5 ± 2.3^a	0.00
PDM	15.4 ± 0.5^a	86.3 ± 2.5^a	65.1 ± 0.7

The extraction efficiency (EE) was calculated considering 17.84% of oil contained in the olives.
Stone recovered was calculated considering 12.00% (dried basis) of stones contained in the olives.
Same letters in the same column indicate not-significant difference among mean values (ANOVA and HSD test, *P* < 0.05) for the two trials (HC and PDM).
HC, hammer crusher; PDM, partial de-stoner machine.

the horizontal centrifugation. Thus, it is important to reduce the viscosity before the olive paste enters the horizontal centrifuge. To achieve this goal the olive paste is subjected to thermo-mechanical conditioning, through malaxation, and to the addition of water before the horizontal centrifugation. Therefore, further investigations are necessary in order to verify if the viscosity decrease due to the absence of an olive stone fraction could lead to a decrement of malaxation time or to an increment of the horizontal centrifuge's flow rate.

Quantitative performance of the virgin olive oil extraction plant
The extraction plant's performances, shown in Table 1, have been calculated considering that the oil percentage in the olives was 17.84% and the stone percentage in the olives was 12 % (dried basis).

Table 2. Qualitative index and phenolic content

Test	Free acidity (%)	Peroxide value (meq [O_2] kg^{-1})	K232	K270	Total phenolic content (mg kg^{-1})
HC	0.50 ± 0.03^a	5.5 ± 0.1^a	1.84 ± 0.02^a	0.13 ± 0.01^a	342 ± 10^a
PDM	0.46 ± 0.02^a	4.8 ± 0.1^b	1.81 ± 0.02^a	0.12 ± 0.01^a	348 ± 14^a

Different letters in the same column indicate significant difference among mean values (ANOVA and HSD test, $P < 0.05$) for the two trials (HC and PDM). HC, hammer crusher; PDM, partial de-stoner machine.
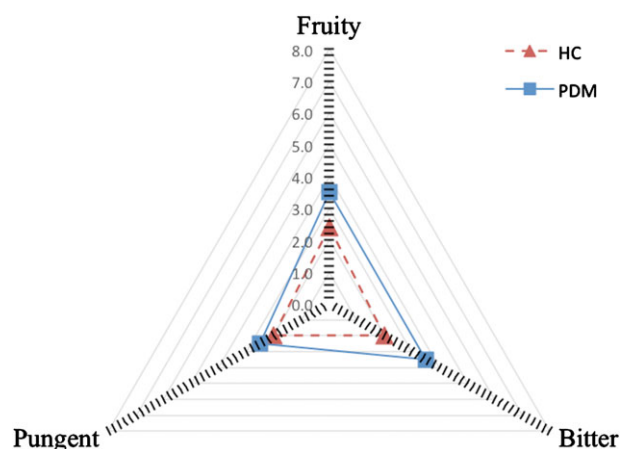
Table 3. Volatiles compound of olive oils obtained from whole and partial de-stoned olives

Compound	RT (min)	HC	PDM
C_5 and C_6 compounds			
Aldehydes			
Hexanal	15.0	1.09 ± 0.01^b	1.28 ± 0.04^a
(E)-2-Pentenal	16.6	0.141 ± 0.005^b	0.181 ± 0.007^a
(Z)-3-Hexenal	17.6	0.051 ± 0.003^b	0.061 ± 0.001^a
(E)-2-Hexenal	21.6	17.03 ± 0.42^b	24.27 ± 0.87^a
2-Methyl-butanal	8.7	0.33 ± 0.02^a	0.26 ± 0.01^b
3-Methyl-butanal	8.8	0.295 ± 0.016^a	0.252 ± 0.009^b
Ketones			
Pentan-3-one	10.8	4.09 ± 0.31^a	4.23 ± 0.17^a
Penten-3-one	12.5	0.31 ± 0.01^b	2.42 ± 0.19^a
Alcohols			
Pentanol	23.1	0.088 ± 0.002^a	0.078 ± 0.006^b
Penten-3-ol	18.8	1.24 ± 0.08^a	1.31 ± 0.10^a
(E)-2-Pentenol	26.0	0.102 ± 0.008^a	0.091 ± 0.007^a
(Z)-2-Pentenol	26.4	0.65 ± 0.02^a	0.70 ± 0.05^a
Hexanol	27.9	1.98 ± 0.06^b	2.15 ± 0.05^a
(E)-2-Hexenol	30.2	4.14 ± 0.11^a	3.79 ± 0.26^a
(Z)-3-Hexenol	29.3	0.233 ± 0.009^a	0.231 ± 0.006^a
2-Methyl-propanol	15.8	0.279 ± 0.020^a	0.218 ± 0.006^b
2-Methyl-butanol	21.0	0.156 ± 0.012^a	0.109 ± 0.005^b
3-Methyl-butanol	21.1	0.66 ± 0.03^a	0.47 ± 0.02^b
Other volatile compounds			
Acetic acid ethyl-ester	8.0	0.78 ± 0.01^a	0.58 ± 0.03^b
3-Ethyl-1,5-octadiene	12.0	0.255 ± 0.008^b	0.293 ± 0.018^a
Sum of all compounds	–	$\mathbf{33.91 \pm 0.55^b}$	$\mathbf{42.96 \pm 0.96^a}$

Different letters in the same row indicate significant difference among mean values (ANOVA and HSD test, $P < 0.05$) for the two trials (HC and PDM).
HC, hammer crusher; PDM, partial de-stoner machine.

Figure 5. Positive attributes of oils obtained using the partial de-stoner machine and the hammer crusher.

Qualitative index and phenolic content of the virgin olive oils analysed

Table 2 shows the effects of the PDM on the main quality indices of the obtained oils. In all samples the main quality indices analysed remained below the limits reported by Regulation EEC/1989/2003 (22) of the European Union Commission, which prescribes free fatty acid content ≤ 0.8 g [oleic acid]/100 g [oil], peroxide value ≤ 20 meq [O_2] kg^{-1}, K232 ≤ 2.50, K270 ≤ 0.22. All samples showed very low percentages of free fatty acids and the data highlighted that the partial de-stoning did not affect oil acidity confirming the results reports in literature.[26] Opposite results were reported by Del Caro et al.[32]

Concerning the peroxide index, the difference between HC and PDM samples was statistically significantly different, in agreement with the results obtained by Saitta et al.[33] but not in agreement with the results obtained by Del Caro et al.[32] or by Gambacorta et al.[34]

Finally, the total phenolic content of oils obtained using PDM and HC did not show significant differences.

The phenolic compounds affect quality of virgin olive oil since they contribute to the sensory characteristics and delay the oxidative degradation process, thus prolonging the product shelf life. Several researches have shown that the total olive de-stoning during the mechanical extraction process of VOO increases the phenolic concentration in VOO.[22,25,35,36]

As already reported by Servili et al.,[23] oils from de-stoned olives showed higher concentrations of phenol compounds than oils from whole fruits, with significant difference

Volatile compounds
The influence of PDM on volatile compounds in the extracted oils has been investigated. All analysed EVOOs showed significant modifications in terms of volatile compounds.

As reported in Table 1 no significant differences were registered for Y and EE in both trials. As reported in Amirante et al.,[22] the decanter decreased its efficiency when totally de-stoned pastes were used, whereas the present study shows there were no losses in efficiency when partially de-stoned olive pastes were processed. This means that probably an amount of about 40% of the stone fragments in the olive paste is sufficient to avoid the technological problems during the malaxation and centrifugation reported in the introduction section.

This result appears to be very important for the use of de-stoning systems in the mill, also considering the percentage of recovered stone (about 65%) to be used for energy production or other purposes.

The identified volatile compounds, including C5 and C6 compounds classified in aldehydes, ketones, alcohols and other volatile compounds, are reported in Table 3. All of these compounds are known as contributors to the olive oil aroma.

In both trials, (E)-2-hexenal, a product of the lipoxygenase pathway,[37] which provides the typical 'green note' of olive oil, resulted the C6 dominant aldehyde. (Z)-3-Hexenal, (E)-2-pentenal, and hexanal were detected in lower quantity than (E)-2-hexenal but all of the five aldehydes resulted statistically plentiful in the trial PDM. On the other hand, despite 2- and 3-methyl-butanal being statistically different among the trials, they were detected in a higher amount in CM than PDM. In the other volatile compounds, aldehydes including 2- and 3-methyl-butanal (sweet, fruity, malty notes),[38] come from possible fermentations or amino acid conversion pathways. If present in large amounts, these aldehydes are generally negatively attributed to off-flavour tastes.

Similarly, pentan-3-one was also among the most abundant ketones, but it did not showed statistical differences among HC and PDM trials. On the contrary, penten-3-one was statistically different among the trials. Penten-3-one is usually found in oils principally produced from unripe olives. This compound has been attributed to fruity, green and pleasant scents[39,40] and positively correlated with pungency and bitterness,[41] but has also been associated with a metallic off-flavour.[42]

Alcohols identified included mainly C5 and C6 compounds, such as pentanol, penten-3-ol, (E)-2-pentenol and (Z)-2-pentenol, (E)-3-hexenol and (Z)-3-hexenol, (E)-2-hexenol and hexanol, 2-methyl-propanol, and 2- and 3-methyl-butanol. All of these compounds derive from the lipoxygenase pathway.[43]

(Z)-3-Hexenol has been negatively associated with bitter taste. Hexanol and (E)-2-hexenol have both been considered as eliciting odours that are not very agreeable,[41] whose accumulation was shown to be favoured by high malaxation temperatures. Results are statistically different among trials.

These results are in agreement with those reported by several authors who have shown that olive stoning during the mechanical extraction process of EVOO increases the composition of volatile compounds produced by the LOX pathway, increasing the concentration of those volatile substances correlated to the 'green' sensory notes. These results are particularly important, because they would appear to demonstrate that the enzymes involved in the LOX pathway have a different activity in the pulp and in the seed of the olive.[23]

Sensory evaluation

Figure 5 shows the positive attributes (fruitiness, bitterness and pungency) of oils from whole and partial de-stoned olives, respectively. All oils were free from defects.

After the production, oils from PDM showed a more intense fruity and bitter attributes and a little difference in the pungent attribute than oils from whole olives. In addition, the fruity attribute of the oil from PDM showed green fruity and green almond attribute than the whole oil, which showed ripe fruity and ripe almond. The partial de-stoned oils were more fragrant with respect to the controls and had a delicate, delicious and harmonic aroma and flavour.

The sensory evaluation confirms the results obtained in terms of volatile compounds and is in agreement with data reported in the literature by Servili et al.[23] and Ranalli et al.[27]

CONCLUSIONS

The total de-stoner machines are efficient and capable of separating the olive fruit stone from the pulp. Using the total de-stoner instead of mechanical crusher led to disequilibrium in the process cycle determining an increase of oil lost in the husk and then a reduction in extraction yield. The latter is determined by a reduction in efficiency both in the malaxation process and in the solid–liquid separation process, caused by the total absence of olive pits.

Thus, as this study pointed out, it can be asserted that using the PDM the problems described above were eliminated, allowing the correct functionality of the centrifugal decanter and consequently the correct solid–liquid separation process. In fact, the present research demonstrated that leaving 40% of pits in olive paste (as pits fragments) the EE loss at decanter level is avoided. The EE measured when PDM and mechanical crusher were used did not show statistical differences.

Additionally, it is notable that the oils obtained using PDM are characterised by higher green fruitiness, flavour and aroma with respect to those produced using traditional processing systems. These oils may result in better acceptance by consumers who able to appreciate the sensorial peculiarity of the oils. In addition, the PDM allows the pits recovery to be used as biomass. It is to be noted that nowadays the goal of environmental sustainability is oriented to the use of renewable energy instead of fossil fuels and the global goal is to increase the use of biomasses for energy-consuming processes. In the last years a machine to recover 50% of olive pits from husks was developed and inserted in olive oil plants but its use represents an additive cost for the miller. The PDM allows substituting the crusher machine and, in addition, produces de-stoned paste with about 60% of olive pits recovered and usable as biomass.

Considering the results obtained, the authors can assert that the use of PDM represent a new solution to obtaining oils having different sensorial characteristics with respect to those obtained through the traditional technology (mechanical crushers) and to produce biomass.

Further investigations are necessary to assess the PDM setting, considering different percentages of olive stones recovered, in order to evaluate yield and olive oil quality.

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