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Article

Development of a Lab-Scale Prototype for Validating an Innovative Pitting Method of Oil Olives

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Abstract: In olive oil extraction processes, different operating methods used for the preparation of olive pastes significantly affect their rheological characteristics, as well as the extraction yields and qualitative characteristics of the oils. To enhance and improve the characteristics of high-quality EVOOs (Extra Virgin Olive Oils), milling technologies have implemented olive pitting in the preparation of olive pastes to be processed for olive oil extraction. Commonly used pitting machines employ the percussion and centrifugal projection of drupes, which often involve the heating of pastes, breaking of kernels, and emulsion of oils. Aiming to improve olive oil pitting processes, the CREA Research Centre for Engineering and Agri-food Processing in Treviglio, Italy, has conceived an alternative method, which is based on the low-speed constriction and mutual abrasion of drupes inside a rotative working chamber. This paper describes the process that led to the hypothesis of an innovative pitting method and to the validation of the hypothesis through the development of a lab-scale pitter prototype. The development steps and the assessment of the results of the prototype trials are reported.

Keywords: pitting; pitted olive oils; EVOOs (Extra Virgin Olive Oils); olive oil quality

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1. Introduction

As is the case for most agro-industrial products, the quality of oil olive yields is mainly subject to the correct adoption and application of all important cultivation practices, to aid the productive potential of the different cultivars, in their various growing areas and orchard managements. All these factors synergically contribute to maximizing the quantity and quality of olives at harvest time [1].

However, the final quality of the olive oils heavily depends on the milling and extraction processes. While it is not possible to obtain valuable oils from low-quality olives, it is quite easy to degrade the quality of the olives at every subsequent stage of the extractive process, up to bottling. These stages include storage time and conditions before milling, crushing machinery and methods, olive paste malaxation parameters, decanter type and settings in the separation of liquid phases from pomace, and so on [2–4].

In line with this perspective, since the 1970s, oil extraction technologies and plants have focused not only on maximizing extraction yields, but also on safeguarding and enhancing the qualitative characteristics of the final product [5–8]. These characteristics can essentially be attributed to two types of substances: one is phenolic compounds, which cause hints of "bitter" and "spicy", and exert a strong antioxidant and nutraceutical action; the other consists of a wide range of volatile substances, which cause the "fruity" flavors characteristic of different cultivars, whose extremely diverse intensities depend both on the olive cultivar and grove conditions and management, as well as the harvesting time and methods.

Therefore, the goals of oil extraction techniques can be summarised as follows:

- maximizing extraction yields while preserving the integrity of triglycerides and minor oil components;
- enhancing or limiting some enzymatic activities to balance the organoleptic paths of the oils.

Different olive milling and management systems significantly affect the amount of phenols and other volatile compounds in extracted oils [9–11]. However, although the effects on the final product will differ, no crushing system may be considered better than another.

In general, stone mills enhance the oxidation of phenols, as the olive paste gets mixed for a long time while exposed to the air; they can be useful for balancing the taste of cultivars that produce excessively bitter and spicy oils. On the other hand, disc crushers, especially if hammered, can be more useful in processing cultivars with lower phenolic substances, because reducing exposure to atmospheric oxygen and overheating the olive pastes inhibits the activity of enzymatic pools [12–18].

In the early 2000s, interest in producing and promoting high-quality EVOOs (Extra Virgin Olive Oils)—for their health benefits and peculiar organoleptic characteristics—led to the technological innovation of implementing olive pitting in the production of olive pastes to be processed in extraction systems.

This method integrates with or replaces the crushing phase, resulting in advantages in terms of maximizing the chemical and organoleptic quality of the oils, as compared to what is obtained from the milling of the whole drupe. Although the absence of pits fragments makes for a less efficient malaxation and reduces the draining of the liquid phase of olive pastes in the decanter during the centrifugation, these negative aspects could partly be solved by increasing the malaxation time and optimizing the decanter setting, thus reducing the mass flow rate [19–21]. Olive pitting lowers the thermal stress of olive pastes and improves their rheological characteristics (higher moisture and oil content, and lower acidity and peroxide values). This increases the Rancimat induction time, allowing the olives to gain five to six more months of shelf life [22–27], another added advantage of pitted EVOOs; although other authors found no difference between pitted and unpitted olive oils in analytical parameters, nor in taste panels [28]. These characteristics can largely compensate for the losses in extraction yields, amounting to 0.5–1.0%, when compared to whole drupe processing in continuous cycles. The above is also due to the reduction of raw material volumes, ranging from 18 to 22%, depending on the pulp/pit ratio of treated drupes [29–31].

Another added advantage of olive pitting is the recovery of polyunsaturated fatty acids (PUFA) and other minor components from olive stone seeds, which constitute a second raw material in the cosmetics and pharmaceutical industry [32–34]. Moreover, the woody part of the pits provides a sustainable energy source [35,36], while pitted pomace can be used as a component for livestock feed and/or biomass composting [37–39].

The commonly used olive pitting machines separate the pulp from the pit by percussion and centrifugal projection of the drupe with a rotative axle, with speeds between 800 and 1400 $r \times min^{-1}$ within a fixed cylindrical grid, with a 3–5 mm diameter hole [40,41].

To avoid the effects of violent milling (i.e., emulsification) and obtaining pulp-only oils, in addition to whole kernels used as a raw material for other agro-industrial products, different pitting solutions could be developed, especially in light of the lack of research and literature regarding these possibilities.

The hypothesis of this work is to devise an innovative "low-speed" olive pitting method as an alternative to percussion and centrifugal projection for the separation of pulps from cores. With this purpose and to assess its feasibility, the CREA-Research Centre for Engineering and Agri-Food Processing in Treviglio, Bergamo, Italy, has patented a new method and developed a specially made lab-scale prototype.

2. Materials and Methods

2.1. Theoretical Conceptualisation of the Pitting Method

The preliminary theoretical conceptualisation of the pitting method identified the constriction and mutual abrasion of the drupes as an alternative hypothesis to percussion and centrifugal projection, in order to generate the forces needed to separate the olive pulps from their cores. It was hypothesised that this result could be obtained with the help of a low-speed rotary mechanism that would process the olives on a continuous basis from an inlet window, in a variable volume working chamber featuring a forced pulp-extrusion and pit-expulsion pathway. This process is intended to reduce olive paste heating and oil emulsion, thus enhancing their rheological characteristics as well as facilitating the next oil extraction steps.

To achieve this goal, a laboratory-scale prototype was developed, adopting and testing different forms of working chambers, and various kind of bulkheads, to optimise the pathway of the drupes, the extrusion of the pulps through the holes of the base grid, and the ejection of whole and cleaned pits through a peripheral outlet.

The prototype was developed using the method of trial and error, which entailed trying out conceptually plausible solutions to the problem, testing and then discarding the false ones as erroneous. This method assumes working with an adequate number of experimental solutions, as one solution after another was put to the test and eliminated [42].

A decreasing volume was obtained by creating the upper part of the bell-shaped separator, higher in the centre, towards the induction chamber, gradually lower towards the periphery, and with the lowest point, corresponding to the exhaust outlet, adjustable according to the transverse diameter of the pits (Figure 1).

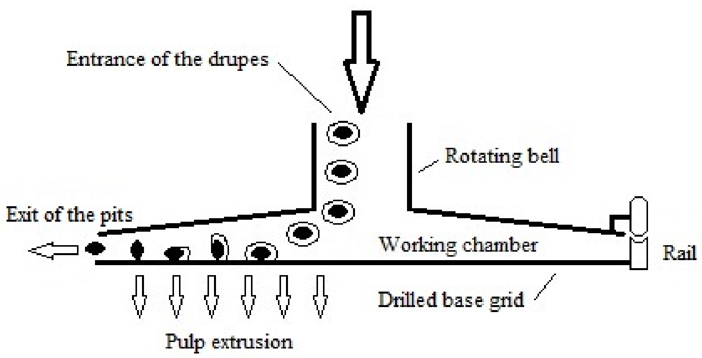


Figure 1. Conceptual scheme of the pitting prototype.

The removable drilled circular base was connected to the machinery by means of a tripod support as body, featuring a rail for the rotating bell cover, on the inner surface of which, different conformations were built and tested for the working chamber.

2.2. Test Conditions and Analysis on Olive Saples

To evaluate the mechanical efficiency of the prototypes, the pitting tests were performed with different olive samples, as they became available on the market.

For the assessment of the final prototype and patented pitting method, olive samples were used from a Cassanese cultivar; they were supplied by the CREA experimental farm in Pescara, Italy, and selected according to a homogeneous 4–5 Maturity Index (MI) (Figure 2).

To compare the rheological characteristics of the olive pastes produced and the pitted residues (pulps and unextruded skins), and to have an analytical feedback for further validation of the patented method, a 5 kg olive sample was pitted using the prototype. Additionally, another 5 kg olive sample was milled with a mini-crusher and malaxated for about 10 min at room temperature (approx. 16 °C), using a lab-scale malaxer machine.

Figure 2. Drupes used in the pitting tests of the final prototype.

The following analyses were then carried out on the two samples of olive pastes obtained and on the unextruded pitting residual (pulp, skins, and pits):

- dry matter content;
- oil content;
- weight of pit fragments, pulp, and skins.

3. Results and Discussion

3.1. Developing an Effective Prototype through the Comparison of Different Working Chambers

Initially, the inner surface of the cover, corresponding to the upper part of the working chamber, was set up with 3 blades whose profiles recalled a logarithmic spiral increasing its radius starting from the centre towards the periphery (Figure 3a). The results of the functional tests show that, with this conformation, the extrusion of the pulp takes place only in the peripheral part of the working chamber, close to the peripheral window where the pits are ejected (Figure 3b).

(**a**) (**b**)

Figure 3. First prototype realisation: (**a**) working chamber with 3 spiral blades; (**b**) extrusion of pitted olive pulp.

To obtain pulp extrusion also in the central area of the drilled base, a different conformation and geometry of the working chamber was evaluated, which led to a second prototype, characterised by sloping and tangential straight wings in the inner surface of the bell (Figure 4a). However, this solution showed no improvement compared to the previous one (Figure 4b).

(**a**) (**b**)

Figure 4. Second prototype realisation: (**a**) working chamber with multiple tangential straight wings; (**b**) extrusion of pitted olive pulp.

It was therefore felt that a factor other than the geometry of the working chamber had greater influence on the desired abrasion and constriction effect. The hypothesis developed following the experimentation on the second prototype was that the gradient of the bell was too high, meaning that the distance between the lower and upper surface of the working chamber in the initial and central part of the pathway of the drupes was too excessive for the size and mass of the prototype. This hypothesis was supported by the fact that pulp extrusion occurred only in the peripheral part of the machine, where the height of the working chamber was lowest, and the force applied to the single drupe was highest.

Based on these preliminary trials, a third prototype (Figure 5a) was then assembled with the aim increasing pressure and constriction on the drupe over the entire extrusion surface. This effect was achieved by conducting the following:

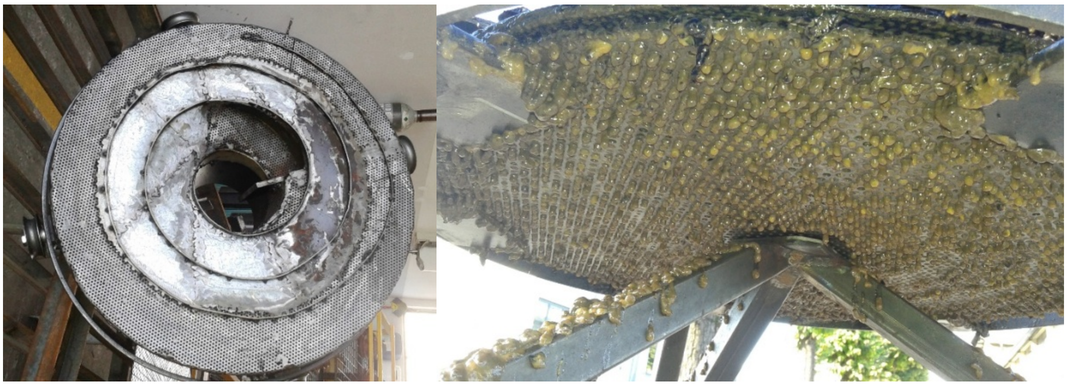
- reducing the volume of the working chamber, from an initial height of 80 mm to 30 mm, lowering by up to 5 mm on the periphery;
- increasing the drupe retention time inside the machine, by lengthening its path with the adoption of two spiral conveyor bulkheads.

Please note that these two solutions indirectly allow another important effect; reducing the number of drupes processed per unit of time, thus increasing the specific amount of pressure for each individual drupe, i.e., the action of abrasion and constriction leading to pulp separation and extrusion (Figure 5b).

(**a**) (**b**)

Figure 5. Third prototype realisation: (**a**) double spiral working chamber; (**b**) extrusion of pitted olive pulp.

The results of the trial with the third prototype show pulp extrusion over the entire surface of the drilled base of the working chamber. This result confirms the hypothesis that the most important factor for the separation of the pulps from their pits is the space between the surfaces of the working chamber, i.e., the specific amount of pressure brought on a single drupe. However, although it was possible for the entire volume of the processing chamber to work, inefficiencies were detected as far as complete cleaning of the pits and extrusion of the pulps was concerned. This led to the consideration that the drupes staying in the machine for a longer time was an additional efficiency factor. The conformation of the working chamber and the arrangement of the conveying bulkheads were then further modified, with the creation of a drupe collection and conveying chamber below the feed window, and the adoption of a single spiral conveyor bulkhead (Figure 6a). A series of straight scrapes were performed on the surface of the drilled base, tangentially to the upper feed window, to increase friction and abrasion. This solution made it possible to enhance both the flow of drupes and the separation of the pulps from the pits (Figure 6b).



(**a**) (**b**)

Figure 6. The final prototype: (**a**) collection chamber below the feed window and a single spiral conveyor bulkhead working chamber; (**b**) extrusion of pitted pulps.

3.2. The Prototype Assembled

In the ultimate version, the prototype (Figure 7) was made of a tripod body, to which flanges were added consisting of a three-phase electric unit, a drilled base plate for pitted pulp extrusion and a circular track. The rotating bell was fitted with four wide-channel wheels on height-adjustable supports, and a handle pulley; the inlet window for the drupes was fixed in the centre of the bell-shaped rotating unit.

Figure 7. Overview of the working elements of the final prototype.

As described above, the inner surface of the bell was shaped like a spiral chamber with a variable volume that guided the drupes through a pathway from the central inlet window up to the peripheral space where the pits were expelled.

In this lab-scale prototype, the drilled base plate had a diameter of 600 mm, while the working chamber had a cone trunk shape with a space between the two surfaces that measured from 30 mm close to the centre to 5 mm at the peripheral expulsion window, and an inner drupe pathway of about 3.4 m, with a volume of about 4 L.

The motion transmission system of the rotating bell was provided by a belt and pulley, and the rotational speed was set to 0.32 Hz (19.2 r $\times$ min^{-1}). With this configuration, a single drupe took about 8 s to get through the working chamber.

The average power absorption of prototype with the chamber full, was 51 W.

With this configuration, the prototype theoretically allowed for the processing of about 1.6 m^3 $\times$ h^{-1} of olives.

3.3. Determination of Moisture and Dry Matter of Olive Pulp Samples

After homogenisation, the pitted and unpitted olive pulp samples were stove dried at 105 °C for 24 h, until a constant weight was obtained. The moisture percentages were then calculated as follows:

$$\text{M}\ \% = 100 - [(\text{P1} - \text{P})/\text{g}] * 100$$

where: P = weight of the empty vessel; P1 = weight of the vessel with dried matter; g = initial weight of fresh matter.

$$\text{dry matter (DM)}\% = 100 - \text{M}\ \%$$

3.4. Determination of the Oil Content of Olive Pulp Samples

The oil content was determined by solvent extraction on dried samples with the Soxhlet system, using petroleum ether at 40–60 °C for 6 h [37].

3.5. Evaluation of Residues

The pitting residue was manually separated by cleansing the pits from the pulp and skin residues, and then weighed.

The samples of whole and pitted olive pastes were evaluated twice after carefully mixing them to make them homogeneous.

The two fractions of pulp and pit fragments were separated from the whole olive paste, through the physical process of continuous water leaching [38].

3.6. Data Analysis of Pitted and Unpitted Olive Samples

Table 1 shows the values of the analyses carried out on the olive paste samples obtained by the crushing of whole olives. Its dry matter content was 39.54%, and its water content was 60.46%; while the pulp result was 85.17%, the pits were 14.83%, and the oil content on fresh matter was 14.36%.

Table 1. Main characteristics of the whole olives paste.

Factor	Whole Olives
Dry matter (%)	39.54
Oil on fresh matter (%)	14.36
Pulp (%)	85.17
Pits (%)	14.83

To calculate the mechanical efficiency of the prototype, the composition of the extruded and not extruded fraction is shown in Table 2.

Table 2. Output of olives fraction obtained with the prototype.

Extruded Fraction (%)		Not Extruded Fraction (%)	
61.76		**38.24**	
Pulp (%)	Pit (%)	Pulp (%)	Pit (%)
100	0	61.22	38.78

The experimental test performed with the prototype showed that the extruded fraction turned out to be 61.76% of the olive mass, which consisted entirely of the pulp. The remaining 38.24% represented the not extruded fraction consisting of 23.41% of pulp and 14.83% of pits.

Table 3 compares the values of the analyses carried out on the whole and pitted olive paste samples. The pitted paste shows lower dry matter and higher oil on fresh matter contents with respect to the milled paste; these differences were mainly due to the absence of pits and skins from unextruded drupes.

Table 3. Analyses of the average characteristics of whole and pitted olive paste.

Factor	Whole Olive Paste (Milled)	Pitted Olive Paste (Extruded)
Dry matter (%)	39.54	32.90
Oil on fresh matter (%)	14.36	18.47

According to these results, we can calculate the mechanical efficiency of the prototype (Table 4); as in the whole olive sample. The pulp turned out to be 85.17%, the efficiency of the prototype was 72.51% ($100 * 61.76/85.17$) and the loss 27.49% ($100 - 72.51$), or $100 * (23.41/85.17)$.

Table 4. Pitting prototype efficiency.

Considered Factor	Values
Lost pulp (%)	27.49
Pitting prototype efficiency (%)	72.51
Oil content (%)	14.36
Pitted pulp (%)	61.76
Oil content in the pitted pulp (%)	11.41
Oil lost with the prototype (%)	2.95

4. Conclusions

In the olive mill industry, olive pastes for oil extraction are usually obtained by stone mills or disc/hammer crushers. In the early 2000s, the increasing interest in producing and promoting high-quality EVOOs (Extra Virgin Olive Oils)—for their health benefits and peculiar organoleptic characteristics—led to the technological innovation of implementing olive pitting in the production of pulp-only olive pastes to be processed in extraction systems [43].

The commonly used olive pitting machines separate the pulp from the pit by the percussion and centrifugal projection of the drupe with a rotative axle in a cylindrical drilled grill. The benefits and the disadvantages of this method have been detailed in the introduction.

Following the approach of obtaining pulp-only olive paste avoiding the effects of violent milling (i.e., emulsification), an innovative "low-speed" olive pitting method has been devised, based on constriction and the mutual abrasion of the drupes, and extrusion of their pulps by pressure.

With this aim, a lab-scale prototype was developed to investigate the main mechanical characteristics required to check the feasibility of the patented method.

In this study, the optimal mechanical solution was found by the "trial and error" method, step-by-step testing, discarding ineffective solutions, and consequently modifying the specific parts identified, until the achievement of an adequate mechanically functioning final prototype in terms of separation and extrusion of the olive pulps, given its structural limitations.

The pitting trials performed with the final prototype showed the feasibility of the patented method, both in terms of the separation of the pulps from pits, and in the values of parameters considered from the olive pastes obtained, in line with the data reported in the literature.

This approach had the main aim of mitigating the thermal stresses produced by violent pitting, as well as reducing the amount of processed olive paste by approximately 18–22%, according to the pulp/pit ratios of the olives. The higher humidity of pitted pastes can also facilitate the separation of oil from wastewater and pomace, where, given the same decanter retention time for the paste, processing saw an increase of about 20–25%. Alternatively, extraction yields may be improved given the same processing capacity, by proportionally increasing paste retention time. In both cases, a pulp-only oil with potentially more pleasant organoleptic characteristics and a higher shelf-life can be obtained.

As for the by-products, from the whole stones recoverable with this pitting system, oil and minor components of high added value can be obtained as second raw materials (End of Waste), for cosmetics or the pharmaceutical industry. This can largely compensate for oil extraction losses, compared to the extraction yields of whole olives. Furthermore, the woody fraction of the pits has a market as a high energy renewable fuel, while pitted pomace can be used in the composition of livestock feed or biomass matrices to produce high quality compost.

As for the assessment of the mechanical efficiency of the prototype in separating the olive pulps from their pits, the results that were obtained did not allow for a definitive quantification due to the structural limitations of the small-scale prototype, which required multiple runs of drupe samples for pulp extrusion.

Although a significant percentage of the pulp and skins (27.49%) was expelled with the pits, despite the high MI of the olives used, the extrusion value of 72.51% can be positively considered, in terms of the feasibility of the patented method, given the structural limits of the lab-scale prototype.

This preliminary study highlighted that the factors to be improved in order to maximise the machine efficiency were: (i) the mass of the rotating bell acting on the drupes; (ii) the single spiral shape of the pathway bulkheads; (iii) the drupes retention time, as a function of both the speed of the rotating bell and length of the pathway; and (iv) the diameter of the extrusion holes of the drilled base.

These are the main factors that could lead to an efficient industrial pitter, achieving the full separation and extrusion of olive pulps and recovering clean and intact pits. The further goal of this project will be the development of a real-scale industrial pitter, to compare the rheological characteristics of pitted paste (i.e., level of emulsification, pulp heating, intensity of pulping) as well as the qualitative parameters of oils obtained versus the current pitting system, from the perspective of implementing this patented method in high-quality EVOOs extraction plants.

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