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Review

De-stoning technology for improving olive oil nutritional and sensory features: The right idea at the wrong time

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ABSTRACT

De-stoning technology has been introduced in the olive oil sector more than twenty years ago. It has not gained momentum because, sometimes, innovative ideas are not accepted since they are suggested at the wrong time or under the wrong circumstances.

Virgin olive oil (VOO) is one of the most popular functional foods, mainly due to its antioxidant properties. These features, as well as other nutritional characteristics are generally enhanced by the de-stoning process. However, despite the improvement of the nutritional value, in the past the de-stoned oil didn't achieve marketing success mainly in relation to technological limitations (*i.e.* low oil yield). Only in recent years healthy properties became an element able to influence consumers' behavior, overcoming the limit of low oil yields and attracting the attention of olive oil producers.

An analysis of the advantages, in terms of product quality and process sustainability, is given in this review. Here, for the first time, the fragmented results reported in literature are critically analyzed underlining the contradictions reported by different authors showing the main reasons for the unlucky fate of this technology in the industrial sector. In the final section the challenges, that future research must focus on, are presented, including emerging technologies in VOO processing. Literature data, for the first time discussed here exhaustively, show that de-stoning technology is a mechanical strategy useful to increase the nutritional and the sensory quality of the product. Moreover, it reduces the depletion of natural resources obtaining a selective crushing of the drupe by removing the stones from the olive paste so increasing the sustainability and efficiency of VOO extraction plants.

1. Introduction

Pitting olives during oil making is an ancient Roman practice described by Cato in the half of the second century B.C. In fact, he recommended not to crush the pit to avoid a bad flavored oil. Columella, in the first century A.C. encouraged to avoid the crushing of pits and spoiling the flavor of the oil (Kapellakis, Tsagarakis, & Crowther, 2008; Niaounakis, 2011). The technique of differential crushing, adapted to the production of the most valuable oils, was forgotten for centuries, until modern centrifugal systems replaced the obsolete presses. Starting from twenty years ago, various olive oil plant manufacturers developed systems to de-pit olives, by crushing only the olive flesh, thus offering to researchers a great opportunity to test the new devices applied to different olive cultivars (Vossen, 2007). Promising results, to the increased quality, were obtained. Unfortunately, the de-stoner machine did not found the expected success because of some negative effects. Considering that the olive oil market was characterized by increasing levels of competition based on cost reduction strategies with negative effects on profitability, the olive millers set aside the de-stoning technology, considering it a threat to their profits. It was probably the "right idea at the wrong time". In fact, nowadays, consumers are in search for healthy, safe, quality and environment-friendly products. After twenty years, this new de-stoning technology can come to the fore gaining the right commercial success since the food market is evolving towards healthy and sustainable products. Hence, de-stoned olive oil could meet this demand earning a premium price able to counterbalance the yield losses. Moreover, the process technologies are quickly improving, developing plant solution able to improve oil extractability, also from de-stoned olive paste.

A recent publication, which proposes a system characterized by a lower environmental impact and a quality improvement of oil based on de-stoning technology, has demonstrated that the topic is still worthy of

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attention (Guermazi, Gharsallaoui, Perri, Gabsi, & Benincasa, 2017). The present review analyzes and compares advantages and disadvantages of this production technique by a multidisciplinary approach. Industrial plant efficiency, environmental impact, healthy and sensory aspects, and the opportunity of by-products valorization are here scrutinized. For the first time it offers to researchers and stakeholders a holistic vision, harmonizing the controversial literature on the product quality and emphasizing the valorization of co-products according to the economic circular approach. The technological advancements applicable for the resolution of the main weakness of this differential crushing method, the slightly loss of oil yields, have also been discussed.

1.1. The virgin olive oil (VOO) elaboration process

A suitable choice and an appropriate use of the various mechanical device combinations of VOO extraction plant, allow to modulate the nutritional and sensory quality of the final product by either enhancing or inhibiting the activity of enzymes present in olive tissues (Amirante, Clodoveo, Leone, Tamborrino, & Patel, 2010; Clodoveo, Hachicha Hbaieb, Kotti, Scarascia Mugnozza, & Gargouri, 2014). Applying the most common extraction techniques to VOO, only a small fraction of the bioactive compounds (2–3%) moves from the fruit to the oil due to the hydrophilic nature of phenolic compounds and the effect of oxidative enzymes on the bio-phenols (Roselli, Clodoveo, Corbo, & De Gennaro, 2017). This evidence underlines that the whole process could be improved by enhancing the concentration of healthy compounds (Clodoveo & Hbaieb, 2013). In particular the crushing step, combined with the malaxation conditions, are involved in the release of phenolic and volatile compounds, significantly affecting the VOO quality due to the freeing of the bioactive compounds and their subsequent dissolution in the oily phase (Amirante, Clodoveo, Tamborrino, Leone, & Dugo, 2012; Clodoveo, 2012).

There are different crushing systems. The common ones are the traditional stone mill and the metal crushers, such as the hammer or disk crusher (continuous machines). The above mentioned mechanical devices produce an olive paste consisting of the fragmentation of the whole olive fruit. An alternative technology in VOO extraction plant is the olive de-stoning machine. The de-stoner is a mechanical system allowing a selective crushing of the fruit flesh excluding the stone from the olive paste. The machine works by a screw feed assembly that conducts the olives towards a suitable perforated container. The olives are then expulsed by a rotating mixer where the pulp is collected and the stones are expelled unbroken and clean. The pulp crosses the basket holes and drops into the hopper underneath. A screw then moves the product from the hopper to a pump that feeds the malaxing machine. Thus, most of the fruit oxidative enzymes, mainly located in the endocarp, such as polyphenol oxidase (PPO) and peroxidase (POD), are removed, protecting the bio-phenols from oxidation. Luaces, Romero, Gutierrez, Sanz, and Pérez (2007) have shown that in presence of seed, the high levels of POD activity detected during the extraction processes play an important role in the oxidation of phenolic compounds. Moreover, when the olive fruits are completely crushed, the presence of olive seed influences the yield of the whole mill plant, because the crushing of pits carries a large loss of mechanical energy due to its conversion into thermal energy. An excessive warming of the olive paste can cause the triggering of thermos-labile enzymes, such as lipoxygenase (LOX) and hydroperoxidelyase (HPL) responsible for the synthesis of volatile compounds.

Why should the de-stoner be considered a good innovation developed in a wrong time? Because, when the innovation was developed the market did not recognize the opportunity given by foods “good-for-the-environment and health”. Nowadays, customer demands have changed and the added value linked to the environmental and nutritional properties of de-stoned VOO can widely compensate the small loss in the oil yield by a premium price gained (Clodoveo et al., 2016; Clodoveo, Camposeo, De Gennaro, Pascuzzi, & Roselli, 2014).

1.2. The de-stoner: a tool to increase the sustainability and efficiency of virgin olive oil extraction plants

Beside the advantages that led to its development as a commercial product, other aspects demonstrate that the de-stoner could represent a useful tool for olive mill companies to move towards a sustainable and efficient use of olive oil extraction plants (Souilem et al., 2017). The use of the de-stoner can improve the efficiency of the mill plant. The stones in fact represent about 25% of the total olive paste volume and their exclusion before the extraction significantly reduces the amount of solid waste processing. The kernel is mainly constituted by polysaccharides (60%), lignin (30%) and only 10% of water. Due to its composition, pit fragments are characterized by a low thermal conductivity, the ability to conduct heat, compared to the pulp fragment. Some physical reactions, such as oily drops coalescence, essential requirements for good oil yields, occur during the malaxation only if the plant material is heated (27 °C) (Amirante & Paduano, 2016). Pit exclusion before the inlet into the industrial plant, ensures optimal heat exchange and represents an advisable energy saving strategy (Manara, Zabaniotou, Vanderghem, & Richel, 2014).

1.3. The de-stoner: a tool to better valorize the VOO waste

Olive stones can be considered an interesting source of powerful phenolic antioxidants compounds, mainly nüzhenide and verbascoside that have a high economic value in cosmetic and pharmaceutical fields (Nunes, Pimentel, Costa, Alves, & Oliveira, 2016). Even if not employed for the antioxidant recovery, olive stones are byproducts useful as renewable energy source characterized by a low N and S percentages, also as interesting fuel for households' stoves (Fantozzi, D'Alessandro, Bartocci, Desideri, & Bidini, 2010).They can also be used for Clean Heat and Power (CHP) applications, *i.e.* systems for a clean, efficient local energy generation. For the olive kernels, it is possible to develop, small-scale thermochemical processes, such as pyrolysis or gasification. These processes give rise to a gas with a high calorific value, useful in internal combustion engines or micro-turbines, and byproducts, such as char and tar that can be applied to the process or for co-generation method. (Amirante, Clodoveo, Distaso, Ruggiero, & Tamburrano, 2016; Bartocci, D'Amico, Moriconi, Bidini, & Fantozzi, 2015).

Moreover, the de-stoned pomace can be easily used as animal feeding, in particular for the residual fat part, as oleic acid and polyunsaturated fatty acids that had beneficial effects for the meat composition (Terramoccia et al., 2013). The contemporary increase of vitamin E concentration in the fat fraction determined a higher oxidative stability (Meo Zilio et al., 2014).

1.4. Influence of the agronomic practices on fruit characteristic and de-stoner performance

There is currently no process in the olive oil industry that can be considered the best one. In fact, the process output depends on many factors including the fruit features (variety, maturity index, pulp/stone ratio, water and oil percentage, *etc.*) as well as the chosen balance between the quality and the quantity of the final product.

Fruit characteristics, such as fruit size and pulp/stone ratio, depend on the genetic profile of the variety (Rosati et al., 2014). In general, large size olive cultivars should give optimal performances with the de-stoner machine. In fact, the de-stoner technique requires a right ratio between pulp and kernel. If the pulp layer is too thin, the mechanical effect of the devices causes the excessive pulverization of the external wood part of the stone with detrimental effect on oil yields. This because the fragmented stone becomes as a sawdust, increasing the adsorbent capacity and causing the loss of the oil fraction.

Also the pulp/stone ratio can be a varietal feature (*i.e.* low in