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Impact of industrial hammer mill rotor speed on extraction efficiency and quality of extra virgin olive oil

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ABSTRACT

Crushing is a key step during olive oil extraction. Among commercial crushers, the hammer mill is the most widely used due to its robustness and high throughput. In the present work, the impact of hammer mill rotor speed on extraction yield and overall quality of super-high-density Arbosana olive oils were assessed in an industrial facility. Our results show that increasing the rotor speed from 2400 rpm to 3600 rpm led to a rise in oil yield of 1.2%, while conserving quality parameters. Sensory analysis showed more pungency with increased rotation speed, while others attributes were unaffected. Volatile compounds showed little variation with the differences in crusher speed; however, total phenols content, two relevant secoiridoids, and triterpenoids levels increased with rotor speed. Hammer mill rotor speed is a processing variable that can be tuned to increase the extraction efficiency and modulate the chemical composition of extra virgin olive oil.

1. Introduction

Extra Virgin olive oil (EVOO) is the oily phase extracted from the just harvested fruit of *Olea europaea* L. exclusively by mechanical means. Considered one of the staples in the Mediterranean diet, it is highly appreciated for its unique nutritional and organoleptic attributes. The sensory characteristics and nutritional properties of EVOO are attributed to its composition of phenolic (Bendini et al., 2007) and volatile compounds (Kalua et al., 2007). These compounds remain in the oil after the extraction process because of the mild conditions used during processing and the lack of ulterior chemical refining.

Processing variables are critical factors affecting yield, quality, and nutritional value of EVOO (Fregapane & Salvador, 2013). Modern continuous process includes crushing of the olive fruit to break the fruit's tissues and release the oil droplets; kneading of the resulting paste to improve phase separation; and centrifugation to separate the oil from the rest of the plant constituents. Among these operations, crushing variables have been studied insufficiently compared to those of malaxation and centrifugation.

The crushing step is a simple physical process used to break the fruit's tissues and release the oil contained in the vegetal cell vacuoles. During crushing, the enzymatic reactions affecting the volatile profile and the phenolic compounds content in the final product are triggered. In addition, the physical properties of the paste going to the malaxation step are established. Therefore, this operation plays an important role in determining both yield and quality of the virgin olive oil produced (Clodoveo, Hbaieb, Kotti, Mugnozza, & Gargouri, 2014).

Many types of olive crushers are currently available to processors. Studies comparing stone mills with hammer crushers (Veillet, Tomao, Bornard, Ruiz, & Chemat, 2009), hammer crushers with disk crushers (Caponio, Gomes, Summo, & Pasqualone, 2003), and hammer crushers with blade crushers (Servili, Piacquadio, De Stefano, Taticchi, & Sciancalepore, 2002) show the impact of these technologies on yield, chemical composition and sensory profile. While all of these options are accessible, the hammer crusher is currently the most widely used in modern continuous facilities due to its robustness and high product throughput. The effect of hammer crusher rotor speed and screen size on olive oil chemical composition has only been studied at laboratory scale. Laboratory trials have shown a relevant impact of these variables on both phenolic and volatile compounds (Inarejos-García, Fregapane, & Salvador, 2011). Nevertheless, these results have not been validated in industrial continuous facilities.

For the last decade, Arbequina, Arbosana and Koroneiki varieties have been planted in super-high-density orchards across California, US.

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As a consequence of the new agronomical practices, olive oil production in the US has been on a rapid incline, increasing from 1000 tons in 2006 to 14,000 tons in 2016 (International Olive Council., 2016). The aim of this work is to study the effect of hammer mill rotor speed on extraction efficiency, chemical composition and sensory attributes of extra virgin olive oil in an industrial mill. Arbosana cultivar grown in a super-high-density orchard has been used as a study case as it is one of the most common cultivars in the US and has not received much attention in literature.

2. Materials and methods

2.1. Olive samples

Three batches of about 25,000 kg of olives (*Olea europaea* L.) from super-high-density Arbosana cultivar were used for this trial. The fruit was mechanically harvested the last week of November 2016 from the same block of trees. The fruit was immediately transported after harvest to the processing plant located in Lodi, California, US, and milled within 14 h from the beginning of harvest. Maturity index, moisture content and fat content were measured and considered as homogeneity indicators of the fruit (Table 1).

2.2. Olive oil extraction

The olives were milled with a hammer-crusher (Manzano MT-50) operating at 2400 rpm, 3000 rpm and 3600 rpm, using a screen size of 6 mm. After crushing, the paste was transferred to the malaxer (EXNI Termobatidora WS-8000). After malaxation (60 min at 27 °C), the paste was pumped into a horizontal centrifuge (GEA RCD 535) with a processing capacity of 6000 kg/h. Finally, the oil was cleaned with a vertical centrifuge (GEA OSD 50), operating at 6700 rpm. Experiments were performed in duplicate and run in random order. Temperature of the olive paste right after crushing remained in the range of 22 °C ± 1 °C for all the trials.

2.3. Moisture content

Olive paste (60 ± 0.1 g) or olive pomace (100 ± 0.1 g) were weighed in a 600 ml beaker and placed in the oven at 105 °C for 12 h or until constant weight. The beaker was transferred to a desiccator and the weight of the dry paste registered after 2 h. Moisture content as well as the other determinations which are going to be described were carried out in duplicate.

2.4. Fat content

Previously dried sample (paste or pomace) from moisture analysis (20 ± 0.1 g) was weighed in a cellulose extraction thimble, placed in the soxhlet extractor, and extracted using *n*-hexane for 6 h. Once the extraction finished, solvent was distilled in a rotary evaporator and residual solvent was eliminated from the oil by placing it in an oven at 105 °C for 3 h. Fat content was expressed as wet basis and calculated according to:

$$FC_{paste/pomace} = \frac{FC_{drybasis}}{1-\left(\frac{MC}{100}\right)} \quad (1)$$

where MC is the moisture content of paste/pomace and $FC_{drybasis}$ the fat content of paste/pomace expressed in dry basis.

2.5. Efficiency

In order to calculate the extraction efficiency, samples of olive paste after crushing and pomace from the decanter were pulled at three different time points during each experiment. Each pulled sample was prepared and the moisture and fat content was determined according to the previously described methodologies. Efficiency was calculated as follows:

$$Efficiency\ (\%) = \frac{(FC_{paste} - FC_{pomace})}{FC_{paste}} \times 100 \quad (2)$$

where FC_{paste} and FC_{pomace} are the fat content of the paste and the pomace, respectively.

2.6. Quality parameters

Free fatty acids (FFA), peroxide value (PV), and UV absorbances (K_{232}, K_{270}) were determined according to AOCS standard methods Ca 5a-40 (09), Cd 8b-90(09) and Ch 5-91(09) (American Oil Chemist's Society, 1998), respectively.

2.7. Diacylglycerols (DAGs)

The International Organization for Standardization (ISO) standard method (ISO 29822:2012) (with slight modifications) was adopted for DAGs analysis. Sample (0.1 ± 0.01 g) was dissolved in 1 mL of toluene and loaded onto a 1000 mg/6 mL solid phase extraction (SPE) silica cartridge (Phenomenex, Torrance, CA, USA) which was previously conditioned with 4 mL of isooctane/diisopropyl ether (85:15, v/v). Two 4 mL portions of isooctane/diisopropyl ether (85:15, v/v) were added to wash off the relative hydrophobic compounds including triacylglycerols (TAGs). Two 4 mL portions of ethyl ether were then used to collect the polar fractions, including DAGs. Afterwards, the extract was evaporated to dryness and the silylation reagent (100 µL, 1-methtyl imidazole:MSHFBA, 1:20, v/v) was added to the reaction vial. After being sealed at room temperature for 30 min, the derivatized extract was dissolved in 900 µL of acetone solution and subsequently analyzed by GC-FID.

GC analysis was conducted on a Varian 450-GC (Agilent Technologies, Santa Clara, CA, USA) equipped with a FID. Helium was used as carrier gas at a flow rate of 1.0 mL/min. DAG isomers were separated on a 30 m × 0.25 mm × 0.1 µm DB-5HT capillary column (Agilent Technologies, Santa Clara, CA, USA) with the injector held at 300 °C at a split ratio of 1:20. The GC oven program was initially held isothermally at 200 °C for 2 min, and then ramped at 15 °C/min to 330 °C and held for 8 min. The injection volume was 1 µL. Quantification was achieved by adding up the peak areas of 1,2-DAGs divided by the peak areas of both 1,2- and 1,3-DAGs (DAGs (%)).

2.8. Pyropheophytins (PPP)

ISO 29841:2012 standard method was adopted for PPP analysis. Three 1 mL portions of petroleum ether were used to extract about 300 mg of oil sample on a 1000 mg/6 mL SPE silica cartridge (Phenomenex, Torrance, CA, USA). The sample was then washed twice using 5 mL of petroleum ether/diethyl ether (90:10, v/v). The pheophytin fraction was later eluted using 5 mL of acetone, evaporated to dryness and reconstituted in 1 mL of acetone. An Agilent 1290 Infinity UHPLC separation system equipped with a C18 column (3.5 µm,

Table 1
Homogeneity parameters for the different batches of olive fruit used for the trials.[a]

Analytical determination	Batch #1	Batch #2	Batch #3
Maturity index	1.1 ± 0.1	1.1 ± 0.1	1.1 ± 0.1
Moisture content (g/100 g)	60.5 ± 0.5	59.8 ± 0.5	60.5 ± 0.5
Fat Content (WB, g/100 g)	23.2 ± 0.2	23.5 ± 0.2	23.3 ± 0.3

[a] Values are expressed as mean ± SD.