



Low-frequency, high-power ultrasound treatment at different pressures for olive paste: Effects on olive oil yield and quality

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ABSTRACT

Ultrasound technology was employed to test its action on the extraction of olive oil at the industrial scale. Because of its mechanical effects, ultrasound waves were applied to the olive paste, between the crushing and malaxing operations. Comparative experiments were performed between traditional extraction processes and the innovative extraction process, with the addition of the ultrasound treatment. Different levels of pressure were tested on olive paste, using four different olive cultivars. Pressure level played an important role in olive oil extractability. When ultrasound was subjected to olive paste with a pressure of about 3.5 bar, there was a significant increase of extractability compared to the traditional process. On the other hand, there was no significant effect between ultrasound treatment and traditional technology on extractability when ultrasound at a pressure level of 1.7 bar was used.

1. Introduction

Ultrasound technology is used in the food industry to develop various effective and reliable food processing applications. The most common applications in the food industry include cell destruction and extraction of intracellular material. Ultrasound (US) waves are mechanical waves having a frequency range of 20 kHz – 10 MHz. They produce mechanical effects that increase the modifying properties of certain solids and alter liquid–liquid and gas–liquid systems [1,2]. Further subdivisions within this range have been identified [3], and they have substantially different characteristics, depending on the frequency at which they are generated and on the amount of energy generated by the acoustic field [3]. In particular, high-energy US characterized by low frequencies (20 kHz–100 kHz) are implicated in the cavitation phenomena due to the mechanical effect of the waves. The influence of US (when the frequency approaches 20 kHz) is based on the formation, growth, and collapse of small bubbles in a liquid; this mechanism is called ‘cavitation’. The bubbles then grow larger by absorbing the gas or vapour present in the medium over several cycles. The bubbles just formed then collapsed in the second stage of the cavitation cycle to release the energy absorbed and to give rise to mechanical effects such as local heat and high pressure [4–6]. The resulting stresses and the repeated collapse of the bubbles bring about damage to the walls and surfaces of the particles [7]. Although

cavitation is considered an event to be avoided in many fields, in other specific fields, such as the olive oil extraction process, it can be useful.

Recently, an extended frequency range of US, from 400 kHz to 2 MHz, has been tested in different applications, such as for the improvement of oil recovery and milk fat creaming acceleration [8] or for palm oil extraction in a semi-industrial plant [9].

In recent years, US technology has been applied to the olive oil extraction process due to its positive effects on the yield and quality of the olive oil. Virgin olive oil extraction consists of five main operations: (i) fruit cleaning; (ii) preparation and conditioning of the paste; (iii) separation of the solid and liquid phases; (iv) separation of the liquid phases; and (v) olive oil storage [10–15].

The effect of low-frequency US in an olive oil extraction process was reported in different papers such as Jimenez et al. [16], and Bejaoui et al. [17], where the authors found positive effects on the extraction process.

In research by Taticchi et al. [18], a high-power US device was introduced in an industrial plant. Research has shown that the sonication of olive pastes led to a significant increase in extraction yield and to the enhancement of phenol content, compared to the oil extracted using a traditional process at an early maturity index.

Relying on these perspectives, over the past few years, high frequency US (> 1 MHz) was used in the olive oil extraction process. The results showed that the chemical and physical effects related to cavitation were minimal, while the effect of acoustic flow was predominant; high frequency

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separation was based on the principle of displacing suspended particles or droplets exposed to an ultrasonic standing wave field [19–22].

As with all other more innovative processing technologies, US wave treatments (both with low and high frequencies) is not a standard technology and therefore must be studied and developed for each type of application before its commercial use. In the olive oil extraction process, the application of US improved the process, in particular helping the malaxation operation and exploiting the positive effects of this treatment (i.e. mechanical and/or chemical and physical effects on the olive paste matrix). The effects of this technology are considered interesting in the olive oil industry, mainly due to their implications to improve the qualitative characteristics and extractability of extra virgin olive oil. However, the interaction of the acoustic energy with a matrix (i.e. olive paste) mainly occurs through a liquid medium; if the implosion of bubbles creates an unusual substrate for chemical reactions implicate on the quality characteristics of olive oil, at the solid and liquid interface, even the water jet formed by transient cavitation might contribute to changes in the rheological properties with positive feedback on quantitative characteristics of the food process, i.e., the olive oil extraction yield.

Consequently, a parameter that could certainly have a strong impact on the effect of US in the olive oil extraction process is the pressure level generated in the US cell. No study has been carried out to examine this interaction.

To this end, a low-frequency ultrasonic device was inserted in an industrial plant for the extraction of oil between a fringe and a kneading machine. Two levels of pressure on olive paste in the US-cell were studied using four different olive varieties.

Finally, the extractability and the quality parameters of the resulting olive oil were evaluated.

2. Materials and methods

2.1. Low-frequency, high-power US machine

The US machine employed for the experimental tests was manufactured by Hielscher GmbH (Teltow, Germany) and installed by Seneco Science (Seneco s.r.l., Milano, Italy). It was composed of a 4 kW power supply, an US generator working at 20 kHz, and an US probe (Cascatrode™, Hielscher GmbH). All functions were controlled by a PLC equipped with a touch screen through which it was possible to set the amplitude value, between 0 and 100%, corresponding to 18–35 μm . The machine was connected between the crusher and malaxer through DN90 connections. The Cascatrode™ was placed in a vertical stainless-steel tube (cell). Olive paste flowed into the cell coming from the side top and exited at the side bottom (Fig. 1). A pneumatic valve was installed on the outlet of the US machine to set the pressure in the cell. A pressure probe was also installed on the output section of the US cell, to monitor the olive paste pressure every second. Data were recorded on a SD-card installed in the PLC. The pressure value determined the US effect on olive paste, in terms of energy transferred. In fact, the higher the pressure value, the more electric power was adsorbed by the machine, because the US frequency must be constant and to do this, the generator had to spend more energy in case the olive paste required more mechanical resistance due to the higher pressure inside the cell. All parameters (electric power, pressure, amplitude and pulsation frequency) were visible in real-time on the display of the PLC.

Considering the chosen frequency and amplitude parameters, the system was able to automatically modulate the electric power used as a function of the pressure detected in the US-cell.

2.2. Plant for olive oil extraction

Experimental tests were carried out in a commercial olive mill (Pietro Leone&Figli, s.n.c., Puglia, Italy). The mill was composed of a defoliator, a washing machine, a hammer crusher (mod. Hammer Mill Crusher; Alfa Laval Corporate AB, Lund, Sweden) with grid hole of

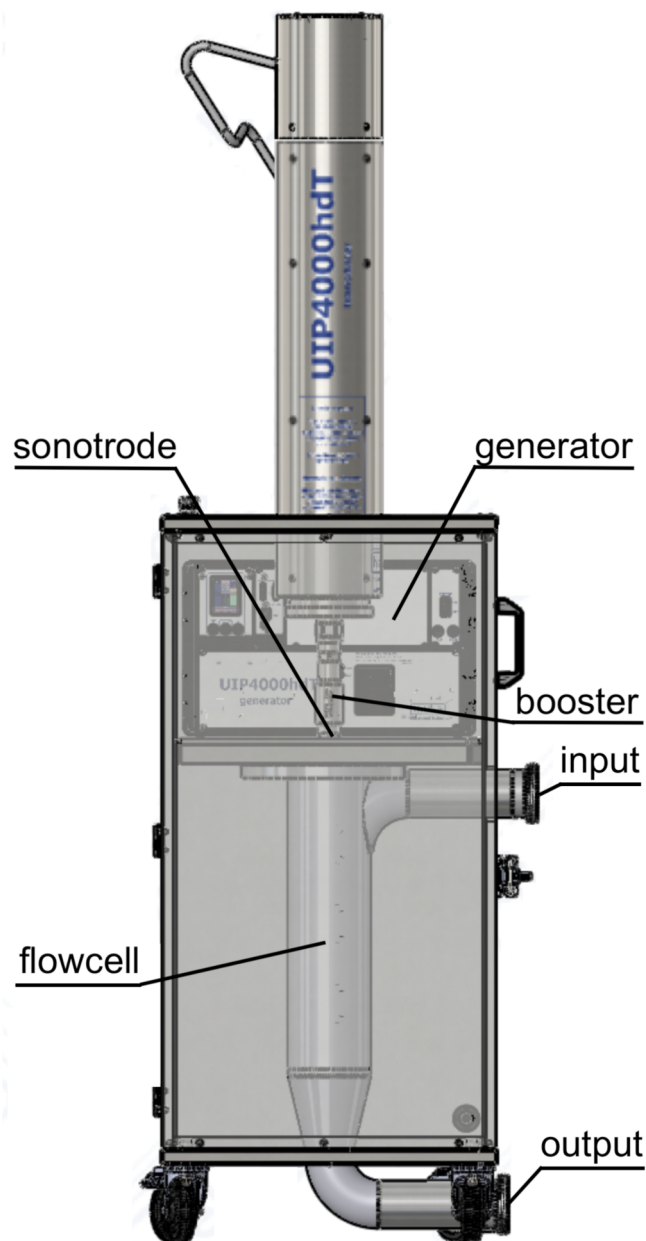


Fig. 1. Ultrasound machine used for experimental tests.

7 mm, a group of six malaxer machines arranged in parallel way, a decanter (mod. NX X32; Alfa Laval Corporate AB) and two vertical plate centrifuges (mod. UVPX 507; Alfa Laval Corporate AB). The decanter was set for a 3-phase way with 10% water added. The mass flow rate was set to 2.3 tonnes h^{-1} for all experiments. For all tests, the malaxation was performed for 30' at $27 \pm 0.5^\circ\text{C}$.

The US machine was installed in the mill between the hammer crusher and the malaxer machine as reported in Fig. 2. By turning the US machine ON or OFF, it was possible to have two different extraction system configurations, a conventional extraction plant (US machine OFF) and an US extraction plant (US machine ON).

2.3. Experimental plan

Experimental tests were performed using olives of the Arbequina, Peranzana, Nocellara del Belice and Coratina cultivars. Olives were mechanically harvested in Foggia and processed within 6 h in order to carry out the tests. For each olive cultivar, five comparative tests

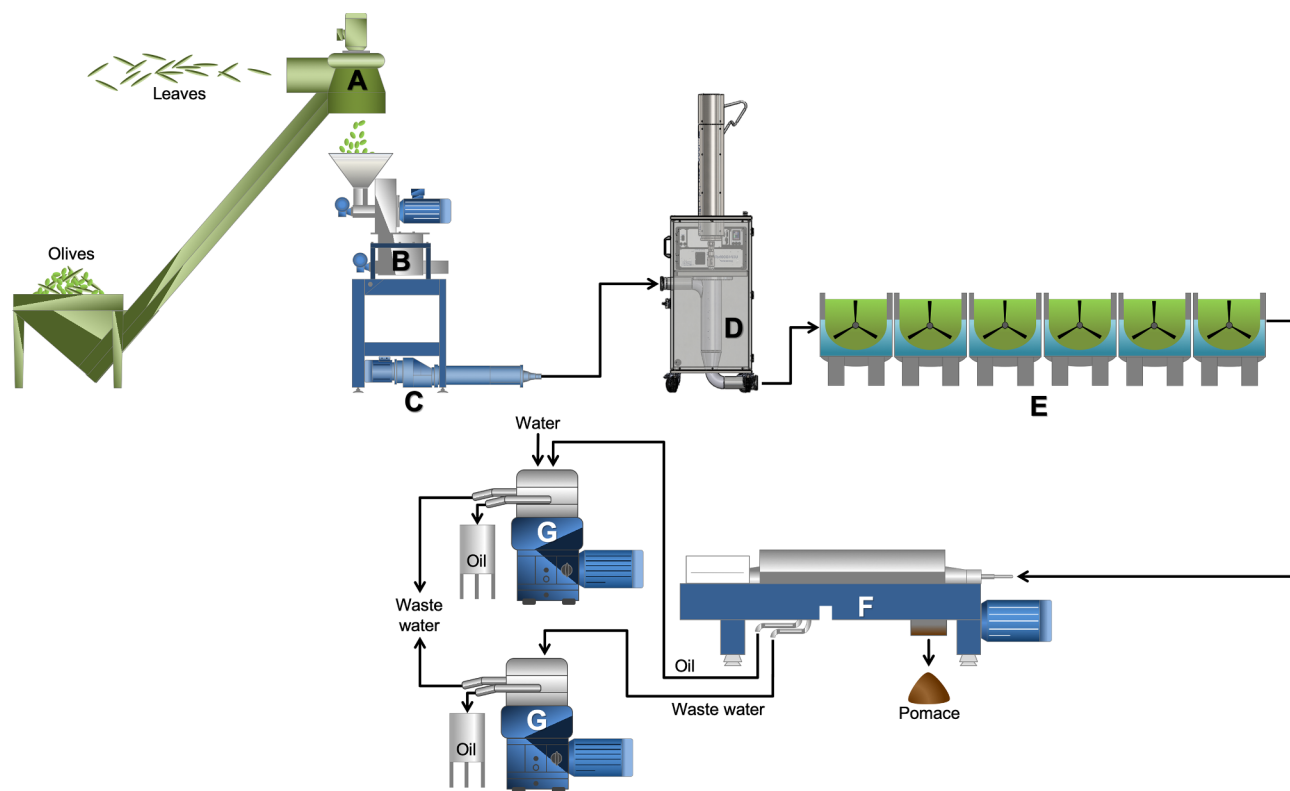


Fig. 2. Scheme of olive oil extraction line: A. cleaning section; B. crusher; C. cavity pump; D. US machine; E. 6-malaxer section; F. horizontal centrifuge; G. vertical centrifuges.

Table 1
Quantitative results and process parameters.

| | Test conditions | Variety | Ultrasound power (kW) | Mean specific energy transferred (kJ kg ⁻¹) | Pressure in US-cell (Bar) | POMACE | | Extractability (%) |
|-----------|-----------------|-----------|--------------------------|--|------------------------------|---------------|--------------|-----------------------|
| | | | | | | Moisture (%) | Oil (%. db) | |
| 1st trial | Control | Arbequina | – | – | – | 56.0 ± 0.6 a | 10.4 ± 0.8 a | 83.5 ± 1.3 a |
| | US 1.7 bar | Arbequina | 2.64 ± 0.26 | 4.13 | 1.7 ± 0.04 | 56.2 ± 0.6 a | 10.7 ± 0.9 a | 84.2 ± 0.3 a |
| 2nd trial | Control | Peranzana | – | – | – | 55.3 ± 0.8 a | 5.6 ± 0.3 a | 83.0 ± 0.6 a |
| | US 1.7 bar | Peranzana | 2.61 ± 0.21 | 4.09 | 1.7 ± 0.02 | 55.6 ± 0.6 a | 5.5 ± 0.7b | 83.1 ± 0.8 a |
| 3rd trial | Control | Nocellara | – | – | – | 56.0 ± 0.5 ab | 7.4 ± 0.7 a | 82.7 ± 1.5b |
| | US 1.7 bar | Nocellara | 2.63 ± 0.25b | 4.12 | 1.7 ± 0.03b | 55.5 ± 0.3b | 7.4 ± 0.8 a | 83.0 ± 1.1b |
| | US 3.5 bar | Nocellara | 3.52 ± 0.38 a | 5.51 | 3.5 ± 0.03 a | 56.5 ± 0.3 a | 5.6 ± 0.6b | 87.1 ± 1.3 a |
| 4th trial | Control | Coratina | – | – | – | 56.3 ± 1.0 a | 8.4 ± 0.5 a | 82.3 ± 0.6b |
| | US 3.5 bar | Coratina | 3.54 ± 0.41 | 5.54 | 3.5 ± 0.02 | 56.4 ± 1.2 a | 6.2 ± 1.4b | 86.9 ± 2.2 a |

Different letters in columns denote significant statistical differences at $p < 0.05$ (Tuckey's test).

Table 2
Standard virgin olive oil parameters specified by the IOC (2017).

| Test conditions | | Variety | Free acidity (%) | Peroxide value (meq O ₂ kg ⁻¹) | K232 | K270 | ΔK |
|-----------------------|------------|-----------|------------------|---|---------------|---------------|-----------------|
| Legal limits for EVOO | | | < 0.8 | ≤ 20 | ≤ 2.50 | ≤ 0.22 | ≤ 0.01 |
| 1st trial | Control | Arbequina | 0.56 ± 0.06 a | 7.57 ± 0.31 a | 1.65 ± 0.05 a | 0.11 ± 0.01 a | 0.002 ± 0.002 a |
| | US 1.7 bar | Arbequina | 0.54 ± 0.01 a | 7.40 ± 0.10 a | 1.63 ± 0.03 a | 0.11 ± 0.01 a | 0.003 ± 0.002 a |
| 2nd trial | Control | Peranzana | 0.44 ± 0.01 a | 6.47 ± 0.21 a | 2.05 ± 0.07 a | 0.17 ± 0.00 a | 0.006 ± 0.002 a |
| | US 1.7 bar | Peranzana | 0.47 ± 0.02 a | 6.63 ± 0.06 a | 2.05 ± 0.03 a | 0.17 ± 0.01 a | 0.004 ± 0.003 a |
| 3rd trial | Control | Nocellara | 0.57 ± 0.01 a | 7.53 ± 0.01 a | 2.21 ± 0.07 a | 0.15 ± 0.01 a | 0.002 ± 0.010 a |
| | US 1.7 bar | Nocellara | 0.57 ± 0.01 a | 7.53 ± 0.25 a | 2.16 ± 0.05 a | 0.15 ± 0.02 a | 0.003 ± 0.001 a |
| | US 3.5 bar | Nocellara | 0.57 ± 0.02 a | 7.27 ± 0.21 a | 2.19 ± 0.07 a | 0.15 ± 0.02 a | 0.003 ± 0.001 a |
| 4th trial | Control | Coratina | 0.23 ± 0.01 a | 6.67 ± 0.25 a | 2.08 ± 0.03 a | 0.17 ± 0.01 a | 0.000 ± 0.001 a |
| | US 3.5 bar | Coratina | 0.25 ± 0.01 a | 6.70 ± 0.26 a | 2.11 ± 0.09 a | 0.16 ± 0.01 a | 0.001 ± 0.001 a |

Different letters in column, for each test conditions, denotes significant statistical differences among means, at p -level < 0.05 (Tuckey's test).

be cultivar dependent, with probably different impact of the acoustic cavitation process on the different enzymes of the LOX pathways of different genetic origin and involved in the formation of aldehydes, alcohols and esters [28,29]. However, on the whole, the treatment at both pressure tested did not modify the sum of C₅ and C₆ saturated and unsaturated aldehydes and alcohols, and esters with the exception of a light variability of the sum of esters in Arbequina and Nocellara del Belice EVOOs and of the sum of alcohols and aldehydes in Coratina and Nocellara del Belice EVOOs, respectively (Table 4).

4. Conclusions

The experiments highlighted the effects of US mechanical waves on olive paste, as a way to improve the performance of the extraction process, increasing the extractability of the plant. US waves were applied to olive paste through a Cascatode™, which was in contact with olive paste in a vertical tube. The efficiency of treatment was evaluated by considering the pressure on the olive paste in the ultrasound cell. As indicated, the pressure had an important impact on ultrasound treatment. In fact, increases of extractability were registered when olive paste was treated at 3.5 bar. These results have to be considered when taking into account the short treatment time, considering the olive paste only went through the US-cell once, at a mass flow rate of 2 tonnes h⁻¹.

The ultrasound technology did not determine any alterations to the main legal quality parameters and showed a positive impact to the phenolic composition of EVOO but only when the system operated at highest pressure of 3.5 bar, confirming the importance of the regulation of process pressure to improve the performance of the ultrasound treatment in the breakdown of olive cells and the release of intracellular content. The data of the sum of the main compounds responsible of EVOO sensory notes were not significantly modified by the ultrasound treatment compared to the respective control test, with some limited exceptions. The variability of the amount of single volatile compounds, did not show a common evolution trend, highlighting a high effect in relation to the different genetic origin of olives and to the adjustment of the operative parameters of ultrasonic device. Finally, studies on the investment and management costs of the ultrasound application in a mill could be important for an overall assessment.

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