Effectiveness of the mechanical excitation applied to the olive paste: possible improving of the oil yield, in malaxation phase, by vibration systems

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Abstract

The mechanical vibrations characterized by a frequency lower than 200 Hz could promote the cells breakage and improve the oil extraction process by avoiding, at the same time, the negative effects on the commercial qualitative parameters due to the use of the heating during malaxation. Vibration tests were conducted by means of an electrodynamic shaker in order to find the optimal frequency levels of excitation, able to put in a resonant condition the olive paste. Sinusoidal accelerations at constant acceleration (120 m/s^2), in a range between 5 and 200 Hz were explored. The 50 Hz and 80 Hz frequencies were able to put in resonant condition the olive paste. In the vibrated samples at 50 Hz (15 min of treatment), the maximum increment of the extraction efficiency (about 53% in comparison with the control), was observed. Further studies could be conducted in order to assess the synergic effect of the mechanical vibrations and the malaxation on the oil extraction efficiency, with the aim of reducing the time of the whole phase and avoiding changes in the oil quality traits.

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Introduction

The olive oil extraction process can be divided into three main phases: the olives crushing, the olives paste malaxation and the olive oil separation from water (Uceda *et al.*, 2006).

In the first phase, the olive fruits are broken with the aim of liberate the oil drops contained in mesocarp cells. The olive paste, obtained after the olive crushing, has then to be malaxed to achieve the emulsion breaking, the merging of small droplets of oil into larger drops, and the formation of a continuous liquid phase.

This mechanical process, that will facilitates the subsequent separation step, is considered a key phase of the extraction process for virgin olive oil both in terms of oil extraction yield increasing and preservation of commercial qualitative parameters. During malaxation, chemical and enzymatic reactions take place; these activities can markedly modify the composition of the oil, especially if an excessive heating accompanies the process (Boselli *et al.*, 2009; Clodoveo, 2012).

The formation of the liquid phase can be in fact improved by increasing the temperature of the paste during the malaxation step. The consequent decrease of the paste viscosity helps the formation of the oil continuous phase and raises the oil extraction yield (Inarejos-García *et al.*, 2009). However, it is well known that the malaxation, if severe, can have a negative effect on the oil quality in terms of phenols content and volatile components and in terms of acceleration of oxidative processes (Angerosa *et al.*, 2001; Ranalli *et al.*, 2001).

A great quantity of literature was dedicated to the effect of the time and temperature of the malaxation treatments on the virgin olive oil extraction yield and quality. These works were extensively reviewed by Clodoveo (2012) together with a critical analysis concerning the use of a particular atmosphere composition and coadiuvants (water, salt, hydrated magnesium silicate and calcium carbonate to name a few) during the process. For what concerns the temperature, according to Angerosa *et al.* (2001), an appreciable oil extraction yield can be measured when levels are not higher that 30°C. Passing from 30°C to 35°C, processes responsible of the formation of primary and secondary oxidation products can have an increment together with the activity of the lipase enzymes.

Recentlly, some relative new technologies have been proposed in order to improve the olive oil extraction process by reducing the malaxation process length. These technologies, used in many food applications, are based on ultrasounds (Jiménez *et al.*, 2007; Clodoveo and Hbaieb, 2013) and microwaves (Clodoveo and Hbaieb, 2013).

By using ultrasounds (frequency higher than 16 kHz), two different effects occur in the extraction: one thermal, due to the absorption of the ultrasonic energy from the olive paste and one mechanical that provides cell breaking due to the cavitation effect. By using microwaves (from 300 MHz to 300 GHz), the electromagnetic energy is converted in thermal energy with a final result of the rupture of the cell and the consequent spillage of its content.

Since the application of the cited innovative technologies in the virgin oil extraction process is recent and few studies were dedicated to these topics, many aspects of the application should be cleared, especially the potential negative effects on the oil commercial qualitative parameters.

In order to improve the extraction process and reduce the malaxation length, also the use of the mechanical vibrations (under 200 Hz) during olive oil extraction could be interesting in the olive oil technological panorama. The vibration applied in the *resonant conditions* of the olive paste as pre-treatment and in combination with the traditional malaxator can have a positive effect in terms of extraction efficiency and oil quality. The mechanical vibrations can allow the breaking of the cells and facilitate the next operations without relevant and critical thermal effects.

The present study aims to assess the effectiveness of the mechanical vibrations applied to the olive paste to improve oil yield. Sinusoidal vibration tests will be conducted in the 5-200 Hz frequency range on olive paste after hammer crushing. Comparisons with a vertical malaxator in terms of extraction efficiencies were conducted.

Materials and methods

Olive fruit samples

Correggiolo variety (*Olea europaea* L.) olive samples were collected in October/November 2011 in the area near Rimini (Northern Italy, Emilia-Romagna region, Italy). Olive maturation index (Jaen index) was assessed according to the International Olive Oil Council method (Uceda and Hermoso, 1998), by measuring the average colouring of olive fruits (peel and pulp). The maturation index of the olives of employed varied between 3.59 and 3.70.

Theoretical performance, in term of total oil content of fresh olive samples, was calculated by using the method proposed by Uceda and Frias (1975), giving the value, in weight percentage, of 14.5±1.5.

Oil extraction system

Oil was extracted by using a continuous low-scale plant with a maximum process capacity about 1.5 q/h (Oliomio 150, Tavernelle Val di Pesa, Florence, Italy), equipped with eight hammer crushers, a vertical malaxator composed by 14 blades grouped in two pair (one constituted by six elements and the other one by eight elements) and a two-phase decanter (Figure 1). The rotation speed of the hammer crush and the malaxer were about 2000 rpm/min and 30 rpm/min, respectively. For the experimentation 60 kg of olives were treated for each cycle (3 cycles in total). For each test, a portion of olive paste was collected after crushing and used for the vibration tests; another one was used as control sample and the remained paste was malaxed for about 35 min. The layout of the experimental procedure is shown in Figure 2.

Vibration tests

Vibration tests were conducted by means of an electro-dynamic shaker (S202; Unholtz-Dickie Corp., Wallingford, CT, USA) at Food Science campus (Cesena, Italy). The shaker was driven by an electronic power amplifier (MA240; Unholtz-Dickie Corp.) and operated by a control console (DP 350 Win; Data Physics Corp., San Jose, CA, USA). A steel cylinder (97 mm in diameter × 200 mm in height) was fixed on the vibrating table to contain the olive paste during the tests (about 1000 g for each test). Preliminary tests were carried out in order to identify the optimal frequency levels of the excitation, able to put in a resonant condition the olive paste. To this aim, sinusoidal accelerations at constant acceleration (120 m/s^2) and at frequency linearly increasing with the time (1.62 Hz/s), in the 5-200 Hz range, were used to excite the paste.

During these preliminary tests, the mechanical behaviour of the paste was assessed by means of a piezoelectric accelerometer (4393 V; Brüel & Kjær, Nærum, Denmark) placed inside the cylinder previously filled with the sample and connected to a charge amplifier (Nexus 2692; Brüel & Kjær) (Figure 3). The acceleration signals

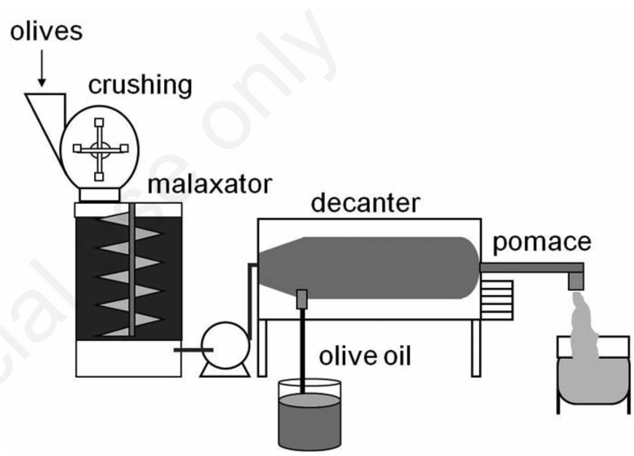

Figure 1. Diagram of the continuous low-scale plan used for olive oil extraction.

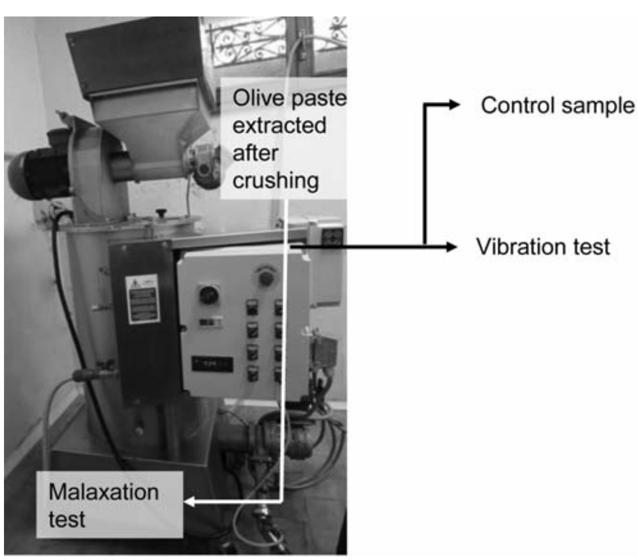

Figure 2. Layout of the experimental procedure.

were acquired and analysed by means of an acquisition board (PCI 6024 E; National Instruments, Austin, TX, USA) and a programme written in Labview version 5.1 (National Instruments). The acquired signals were processed via fast Fourier transform algorithm.

The temperature of the paste can increase by increasing the excitation time (within the same level of the acceleration and frequency) and it is well known that the quality of the extracted oil can be affected by an increase in the temperature (Uceda *et al.*, 2006). For this reason, after the identification of the most convenient frequency levels, two different test durations were carried on. The test durations were defined by carrying out further preliminary tests characterized by sinusoidal accelerations at constant accelerations (120 m/s^2) at the selected frequency levels, but with different durations (from 5 to 55 min, increments of 10 min).

Assessment of the oil extraction efficiency

The extraction efficiency was assessed in terms of grams of oil obtained by centrifugation of 25 g of olive paste into a 50 mL test tube (BD FALCONT^{TM}, San Jose, CA, USA) (3500 rpm × 5 min). These assessments were conducted on the pastes excited by using the electro-dynamic shaker and on the malaxed and on the control pastes. For each sample, five replications were performed.

Immediately after the centrifugation, the liquid phases (oil and water) were poured into another 50 mL test tube, with the aid of a strainer (BD FALCONT^{TM}) and centrifuged again (3500 rpm × 3 min). The paste surface was washed using 10 mL of *n*-hexane. The oil dissolved in *n*-hexane was then transferred in a flask, dried and weighed. During the tests, control samples were stored at about 20-22°C for the same time required for vibration and malaxation tests.

Statistical differences ($P<0.05$) between the vibrated, the malaxed and the control samples were found, in terms of percentage of oil extracted from the olive paste, by using the Student's *t*-test (SPSS 13.0 for Windows; IBM SPSS Statistics, Armonk, NY, USA).

Results and discussion

Vibration tests

Figure 4 shows the olive paste accelerations (m/s^2) analysed in the frequency domain and measured by means of a piezoelectric accelerometer placed inside the sample.

Two acceleration peaks at 527 m/s^2 and at 464 m/s^2 can be respectively observed at 50 Hz and 80 Hz. At these two frequencies, the initial acceleration of 120 m/s^2 was amplified of about four times and the olive paste reached the resonant condition, which was also visually appreciated. At these frequencies the paste clearly appeared released from the

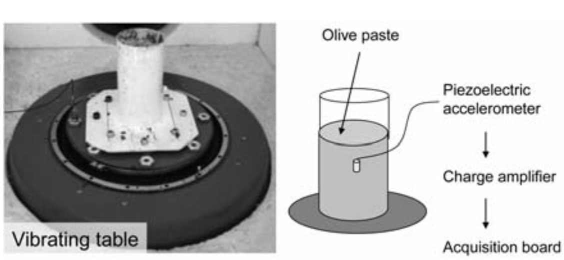

Figure 3. The vibrating table and a detail of the piezoelectric accelerometer placed inside the olive paste during the experimental tests.

system (steel cylinder) and characterized by a whirling motion. Since the 50 Hz frequency showed to produce the highest resonant acceleration of the olive paste, the extraction efficiency was assessed by using these following three vibration treatments: 50 Hz at two durations (5 and 15 min) and 80 Hz for 15 min. At these conditions (frequency and duration of the vibration) a maximum increase of about 2°C was measured in the temperature of the olive paste, being the temperature of the olive paste before the vibrations about 20°C.

In order to assess if the extraction efficiency is related to a specific resonant frequency of the paste or if a narrow range of frequencies can be used, also in consideration of a possible resonant frequency shift due to the different characteristics of the olives, a further vibration treatment was conducted at frequency linearly increasing with the time (1.22×10^{-2} Hz s^{-1}) in the 45-55 Hz range, for 15 min (120 m/s^2).

Assessment of the oil extraction efficiency

The results in terms of percentage of extracted oil from olive pastes, submitted to the different vibration treatments, and to the malaxation process are shown in Figure 5 together with the relative controls.

According to Figure 5, both the vibration at constant frequency and

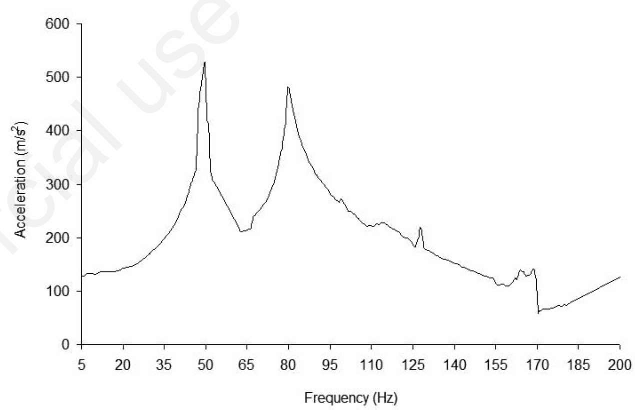

Figure 4. Acceleration (m/s^2) in the frequency domain, measured by the accelerometer placed in the olive paste submitted to a sinusoidal accelerations (120 m/s^2).

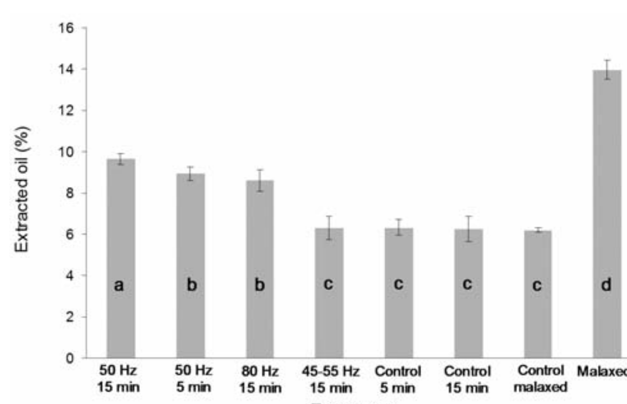

Figure 5. Mean values of the oil extraction efficiency (%) for the vibrated, the malaxed and the control samples. Vertical bars are standard deviations; differences between means with the same letter are not significant at at P<0.05.

the malaxed process appeared to significantly improve the oil extraction (%) respect to the control paste.

The highest extraction (more than the double respect to the relative control sample) was observed for the malaxation process. Since the malaxation involves a greater mechanical stress respect to the mechanical vibrations, this result is not surprising.

For the vibrated samples, the highest percentage of extraction was obtained for the olive paste submitted, for 15 min at 50 Hz vibration (about 53% of increment respect to the relative control sample). Both the frequency and the duration of the vibration significantly affected the extraction efficiency. Even if slight, significant differences were found between the two tested frequencies 50 Hz and 80 Hz (within the same vibration duration of 15 min) and between the two considered durations 5 and 15 min (at 50 Hz).

The treatment conducted by vibrating the paste with a sweep in the frequency range 45-55 Hz for 15 min did not show a significant increment in terms of capacity to release oil in comparison with the control sample.

The olive paste submitted to the sweep, even if vibrated in a range containing the value of 50 Hz, showed a significant different behaviour respect to the samples vibrated at the single frequency 50 Hz. Unobserved improvement in the extraction efficiency in the 45-55 Hz vibrated olive paste can be due to the necessity of conducting and maintaining a vibration exactly at the resonant conditions frequency, for the right time. No significant difference emerged between the three control samples (5 and 15 min of vibration, and the malaxed).

Conclusions

A significant increase in the extraction yield was observed in the vibrated olive pastes. Both resonant excitation frequency and duration can significantly affect the oil extraction. Respect to a control sample, a maximum increment of about 53% of the extraction efficiency was observed at 50 Hz and after 15 min of treatment. After the vibration tests, a maximum increase of 2°C of the temperature paste was measured. The resonant conditions experimentally founded were surely related to the physical-mechanical characteristics of the tested olive pastes and can be affected by several factors such as the cultivar, the maturity stage of the olives and the milling process. What emerged with certainty is that the extractive effectiveness occurred at a precise frequency and, in this sense, it will be necessary to set, from time to time and in relation with the geometry and dimension of a possible real plant, the frequency of excitation more favourable for maximum extraction of the oil.

Compared to the malaxation process, the extraction efficiency of the vibrated oil pastes showed a significantly lower extraction power. This is not surprising because the two methods, the vibration and the malaxation, involve a different mechanical stress to the paste.

Further studies can be carried out in order to assess if the combination of the vibration with the malaxation can positively influence the quality of the virgin oil produced and the energy balance of the process, by reducing the time of the whole malaxation phase.

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