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A kinetic approach to predict the potential effect of malaxation time-temperature conditions on extra virgin olive oil extraction yield

S. Trapani [a], L. Guerrini [b], P. Masella [b], A. Parenti [b], V. Canuti [a], M. Picchi [a], G. Caruso [c], R. Gucci [c], B. Zanoni [a,*]

[a] Department of Agricultural, Food and Forestry Systems Management (GESAAF) – Food Science and Technology and Microbiology Section, Università degli Studi di Firenze, Via Donizetti 6, 50144 Florence, Italy

[b] Department of Agricultural, Food and Forestry Systems Management (GESAAF) – Agricultural, Forest and Biosystem Engineering Section, University degli Studi di Firenze, Piazzale delle Cascine 15, 50144 Florence, Italy

[c] Department of Agriculture, Food and Environment, Università degli Studi di Pisa, Via del Borghetto 80, 56124 Pisa, Italy

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ABSTRACT

An original kinetic study of both oil coalescence phenomena and potential extra virgin olive oil extraction yield (i.e. apparent Extractability Index) was carried out at different malaxation time-temperature conditions using Abencor lab equipment to process olives (Frantoio cv) of a known degree of ripeness.

The apparent Extractability Index was modelled at every malaxation temperature by pseudo first-order kinetics, where the yield rate constant was temperature dependent following the Arrhenius equation ($k_0 = 7.50\ 10^7\ \text{min}^{-1}$; $Ea = 54512$ J/mol). Oil droplet coalescence, which was expressed as a relative variation in the percentage of oil droplets with a diameter of >30 μm, proved to be an time-dependent phenomenon only; the pseudo zero-order kinetics modelling was statistically significant, where the coalescence rate constant was equal to 0.033 min^{-1}. The above kinetics were applied in order to propose a synoptic chart to predict the potential effect of malaxation in isothermal conditions on EVOO extraction yield.

1. Introduction

Extra virgin olive oil (EVOO) production continues to be the main source of income for olive growers, despite the many strategies developed to make a profit from olive oil by-products (Masella et al., 2014; Parenti et al., 2014).

In general, the oil content of ripened olive oil fruits varies between 10 and 30% on a fresh weight basis (Clodoveo, 2012; Caruso et al., 2013; Nasini e Proietti, 2014). EVOO is considered to be mechanically extracted in the correct manner when the "*Extractability Index – EI*" (i.e. the percentage ratio between the olive oil extracted and the fruit oil content in the olives) is in the range of 80–90% (Boskou, 1996; Leone et al., 2015a); however, it is not rare to find oil extraction processes with lower *EI* levels (Bejaoui et al., 2016; Leone et al., 2016).

The *EI* depends on both the quality of the olive oil fruits and the operating conditions in the olive mill (Espinola et al., 2011). Malaxation is one of the most important steps affecting yield during the extraction process (Clodoveo, 2012). It consists of slow and continuous kneading of the olive paste to induce oil coalescence phenomena (Ranalli et al., 2003): minute oil droplets merge into large oil droplets, thus creating a continuous liquid phase, which can be mechanically separated from the olive paste (Kalua et al., 2006). After malaxation more than 80% of the oil droplets in the olive paste should have a diameter of more than 30 μm (Martìnez Moreno et al., 1957).

Moreover, malaxation reduces the emulsions formed during olive crushing allowing the recovery of another fraction of the oil (Di Giovacchino et al., 2002; Ranalli et al., 2003).

In malaxation, time and temperature are the main operating conditions that control the above phenomena, affecting the oil process yield. Generally, the literature data indicate an increase in yield when there is a rise in the time-temperature values of the olive paste malaxation (Di Giovacchino et al., 2002). However, the literature data from the experiments were not uniform and no modelling based on pseudo *n*-order kinetics was carried out of either the phenomena involved or relationships of relevant rate

* Corresponding author.
E-mail address: bruno.zanoni@unifi.it (B. Zanoni).

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constants with temperature. Table 1 sums up some remarkable literature data (Ranalli et al., 2003; Kalua et al., 2006; Aguilera et al., 2010; Espinola et al., 2011).

Several enzymatic phenomena also occur during malaxation, modifying the quality characteristics of the extracted oil. Oil secoiridoids and volatile compound contents depend on the temperature, time and oxygen level during malaxation (Clodoveo et al., 2014; Tamborrino et al., 2014; Zanoni, 2014; Clodoveo et al., 2015; Catania et al., 2016). Low temperatures, reduced times and a lack of air are generally considered to be the optimum malaxation operating conditions (Servili et al., 2008; Migliorini et al., 2009); they are tendentially the opposite conditions to those previously shown for the process yield. All these are reasons for the choice by some oil manufacturers to extract EVOO under malaxation time-temperature conditions that penalize the oil extraction yield.

EVOO is highly prized for its flavour as well as its healthy characteristics, but a high EVOO recovery also has to be sought. Hence, it should be desirable to strike a balance between oil yield and oil quality characteristics in relation to the quality of olives and the type of olive press, but this requires studies that approach the phenomena involved in malaxation in a predictive manner.

Since it was thought that a malaxation optimization study should start from a mathematical forecast of the oil process yield, the aim of this work was to check whether a time-temperature kinetic study could be applied in order to predict both oil coalescence phenomena and the potential effect of malaxation on extraction yield.

2. Material and methods

Two sets of experiments were carried out. The first lab experiments were used to determine the kinetics of both oil coalescence and apparent oil extraction yield during olive paste malaxation at different time and temperature conditions. The second experiments were carried out to compare the above kinetics with the kinetics during olive paste malaxation at industrial scale.

The goal of the industrial-scale malaxation trials was to test if kinetics models could be transferred to a real oil mill. This oil mill therefore had to have comparable operating conditions to those used in the lab trials, namely with olives from the same cultivar and with a similar degree of ripeness. In addition, the malaxation time-temperature conditions had to be within the same intervals as those adopted in the lab malaxation trials.

2.1. Malaxation trials at lab scale

During the 2013 crop season, the olive oil fruits (*Olea europea* L. Frantoio cv.) were supplied by a farm located in San Casciano Val di Pesa (Florence, Italy). The ripe olive oil fruits were picked by hand at 08:00 a.m. at the beginning of November. Approximately 30 kg of olive oil fruits, which presented no infection or physical damage, were quickly transported to the laboratory.

The kinetic study was performed using Abencor lab equipment (Abencor analyser, MC2 Ingegneria Y Sistemas S.L., Seville, Spain). In the oil sector, this is considered a reference for lab extraction tests (Anonymous, 2011), for example in order to assess apparent oil extraction yields with varying olive quality and malaxation operating conditions (Kalua et al., 2006; Espinola et al., 2011). With respect to its usual use, the equipment was used both for the olive crushing and olive paste malaxation, but not for the olive paste centrifugation. A table centrifuge was used for the olive paste centrifugation to enable the measurement of an apparent oil extraction yield on a small amount of olive paste samples, as described further.

Table 1
Some remarkable literature data about effects on yield of malaxation time-temperature conditions.

Lot sample	Processing equipment	Malaxation conditions	Yield determination	Results	Modelling	Reference
600 kg olives of Leccino, Dritta and Coraleo cultivars	Industrial equipment (Rapanelli, Italy)	0, 15, 30, 45, 60 and 75 min at 30 °C	Measurement of an industrial *EI* after oil extraction by a two-phase "decanter" and oil cleaning with a vertical centrifuge	Increase in the *EI* up to 60 min; from 60 to 70 min small decrease in the *EI*	–	Ranalli et al. (2003)
1 kg olives of Frantoio cultivar	Lab extraction unit (Abencor, Spain)	30, 60, 90 and 120 min at 15, 30, 45 and 60 °C	Measurement of an apparent *EI* after oil centrifugation, followed by decanting of oil-water mixture in bottles	Increase in the *EI* with time and temperature; at 45 °C lower *EI* values than at the other temperatures	–	Kalua et al. (2006)
5000 kg olives of Picual cultivar from three different crop seasons	Pilot plant (Pieralisi, Italy)	60 and 90 min at 18, 30 and 40 °C	Measurement of pomace oil content on dry weight (*PODW*)[a] after oil extraction by a two-phase "decanter" and oil cleaning with a vertical centrifuge	Tendency of *PODW* to decrease as the time and temperature increase; results vary depending on the crop season	–	Aguilera et al. (2010)
0.5 kg olives of Picual cultivar from two different crop seasons and at different level of maturity index	Lab extraction unit (Abencor, Spain)	Values selected by an experimental design as follows: - time: 5.5, 20, 55, 90 and 104.5 min - temperature: 15.9, 20, 30, 40 and 44.1 °C	Measurement of an apparent extraction yield (g oil/100 g olive paste)[b] after oil centrifugation, followed by decanting of oil-water mixture in a graduated tube and measurement of residual oil content in olive pomace	Positive influence of time-temperature conditions on extraction yield: optimal values of extraction yield from 20.1 to 32.2 and from 73.3 to 90 min	A quadratic empirical model of the extraction yield as a function of malaxation time and temperature conditions and olive maturity index	Espinola et al. (2011)

[a] It can be considered that the *EI* decreases when the *PODW* increases.
[b] If the concentration of oil in the olive paste is known, an apparent *EI* can be calculated from the extraction yield.