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Plant innovation in the olive oil extraction process: A comparison of efficiency and energy consumption between microwave treatment and traditional malaxation of olive pastes

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ABSTRACT

In this study, we discuss the introduction of microwave radiation replacing the malaxation of olive paste and associated experimentation. A major limitation of olive oil extraction plants is the discontinuity in the extraction process due to the current technology used during the conditioning of the olive paste. In this work, a microwave-assisted system was developed and applied in an industrial-scale olive oil extraction plant to preliminarily analyse the installation and determine any advantages to improving the process continuity. The apparatus, which is specifically designed to be industrially implemented, was evaluated in terms of electrical and thermal energy consumption and the extraction yield of the olive oil. Special attention was given to a microstructural investigation of the olive paste using SEM analyses. The microwave treatment does not significantly influence the extraction yield compared with conventional malaxation, but the SEM results demonstrated that the microwave technique efficiently breaks down cell walls and membranes, thus increasing the release of oil. In addition, some benefits are observed that result from making the olive oil extraction process continuous. The results acquired from this study are promising for microwave implementation in olive oil extraction plants in the future.

1. Introduction

The extraction techniques employed to produce olive oil from olives in the last 30 years have not seen the significant innovation necessary to introduce substantial changes in the overall organisation of the mill and the logistics of the process. The most important innovation in olive oil extraction plants was the introduction of the horizontal decanter centrifuge, which allowed the continuous operation of the solid–liquid separation. This innovation has had the effect of rendering obsolete the operations involved in discontinuous pressing (Amirante and Catalano, 1993; Amirante et al., 2010; Daou et al., 2007). The main benefits were the improvement in the olive oil quality by preventing oxidation and the improvement of the management of the mill (Di Giovacchino et al., 2001; Ranalli and Angerosa, 1996; Catalano et al., 2003; Altieri, 2010; Altieri et al., 2013). Time savings, the associated reduction of labour and labour costs, faster and easier cleaning of the equipment and the new layout of the mill that included minor space dedicated to the machines of the process were the main advantages achieved by the continuous machine. This led to the immediate and widespread dissemination of the decanter over the entire world. Currently, if we look at the olive oil extraction process, we realise that all operations are continuous except for malaxation. This represents the major limitation in olive oil extraction plants associated with the continuity of the olive oil extraction process and leads to connection problems between the continuous operations before washing and crushing and those that follow solid–liquid separation and liquid–liquid separation. To overcome these limitations, the current industrial solutions include a series of tanks with a production capacity equal to the throughput of the horizontal decanter centrifuge. The number of malaxers required is decided on the basis of the plant work capacity, the required malaxing time and the average size of the batches of olives. Examined one way, this processing system ensures continuous processing. However, it has many disadvantages due to operating management for the malaxer machine.

The flows of olive paste passing through to the malaxer machine occasionally results in dead spots and stagnation during the loading and unloading phases, which are frequently required

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Nomenclature

MPS	microwave prototype system
EVOO	extra virgin olive oil
PLC	programmable logic controller
U_p	service fluid-paste heat transfer coefficient (W m^{-2} °C^{-1})
U_{air}	service fluid–air heat transfer coefficient (W m^{-2} °C^{-1})
m	mass of olive paste (kg)
C_p	specific heat of olive paste (J kg^{-1} °C^{-1})
T_p	Temperature of olive paste (°C)
T_f	temperature of service fluid (°C)
T_{air}	temperature of atmospheric air (°C)
ΔT_{ML}	logarithmic mean temperature difference (°C)
S_i	internal heat exchange area of malaxer (m^2)
S_e	external heat exchange area of malaxer (m^2)
t	malaxing time (min)
q	thermal energy (J)
DSC	differential scanning calorimeter
Q_{DSC}	heat flow measured by DSC (J s^{-1})
r	DSC scanning rate (°C min^{-1})
w	sample weight subjected to DSC analysis (kg)
w.m.	wet matter
d.m.	dry matter
EY	extraction yield (kg [oil] · 100 kg [olives]$^{-1}$)
W_{oil}	mass of the extracted oil (kg)
W_{olives}	mass of processed olives (kg)
SEM	scanning electron microscope
V	volume of olive paste (m^3)
ANOVA	analysis of variance
R^2	coefficient of determination

to ensure the proper operation of the malaxing process (Amirante et al., 2012; Leone et al., 2014a; Tamborrino, 2014). However, one of the great limitations is control over temperature and time of kneading, which have considerable importance for the extraction yield and olive oil quality. Finally, the management of the malaxing is entrusted to the ability and knowledge of the operators, who have a great influence on the quality of the process. Inadequate management of this phase risks quality degradation and a loss of yield (Aguilera et al., 2010; Inarejos-Garcia et al., 2009; Esposto et al., 2013; Leone et al., 2014a; Gambacorta et al., 2010, 2012; Gomez-Rico et al., 2009; Reboredo-Rodríguez et al., 2014; Tamborrino et al., 2014a,b). Therefore, significant innovation is required to develop a continuous malaxing phase. The direction of academic and industrial research is moving toward the establishment of technological solutions and the development of novel innovations to maximise the productivity of this specific sector. With this in mind, in this work, the authors consider employing microwave radiation in olive oil extraction plants during the malaxation phase. In recent years, microwave processing of food has emerged as one of the fastest heating techniques available and is being investigated in various food processes (Leone et al., 2014b; Singh et al., 2014; Mudgett, 1986; Cheng et al., 2006; Datta, 1990; Cocci et al., 2008; Seixas et al., 2014; Catalano et al., 2013).

Microwave heating is different from other indirect thermal heating methods. Microwave energy heats the food material at the molecular level, which eventually leads to uniform bulk heating. Because the heat originates in the molecules throughout the bulk, the heating process is faster than other known modes of heating in which depend on conventional modes of heat transfer (Schiffmann, 2010; Salvi et al., 2009; Chandrasekaran et al., 2013). In conventional heating systems attached to the malaxer machine, the olive paste gets heated from the surface of the tank to the interior via a thermal gradient, resulting in excess expenditures of time and thermal energy (Comba et al., 2011).

However, microwave heating is characterised as volumetric heating, reducing the thermal gradient and saving thermal energy (Regier, 2014). Thus, the application of microwave energy as a source of heating during the conditioning olive paste may be a cost effective option that can be employed in the olive oil processing industry.

Numerous studies have reported on "no-thermal" effects of food materials exposed to microwaves compared to other thermal processes, and changes in microstructure of food materials (Thostenson and Chou, 1999; Uquiche et al., 2008; Starmans and Nijhuis, 1996; Aguilera and Stanley, 1999; Jiao et al., 2013). A primary goal of this research is to investigate any possible changes in the structure of the olive paste subjected to the microwave treatment to investigate the release of oil drops from the vacuoles of the cells.

To analyse the feasibility of the installation of microwave technology for conditioning olive paste to achieve a continuous process, an industrial apparatus specifically designed and was implemented to analyse the electric and thermal energy consumption, as well as the extraction yield in an olive oil extraction plant. The results acquired from the present study are considered very promising for the future of this technology in this specific field.

2. Materials and methods

2.1. Industrial microwave prototype system

An MPS system was installed in an industrial processing line for EVOO extraction. The MPS (Fig. 1) was fabricated and assembled by EMITECH s.r.l. (Molfetta, Italy). It consists of a reverberant chamber fabricated from AISI 304 stainless steel. Inserted on the side of the reverberant chamber are four TM060 generator heads packaged in a stainless steel cabinet and housing a water-cooled YJ1600 magnetron (Alter s.r.l., Reggio Emilia – Italy), which is powered by four SM1180T power supplies (Alter s.r.l., Reggio Emilia – Italy). The total output power from the four magnetrons is equal to 24 kW.

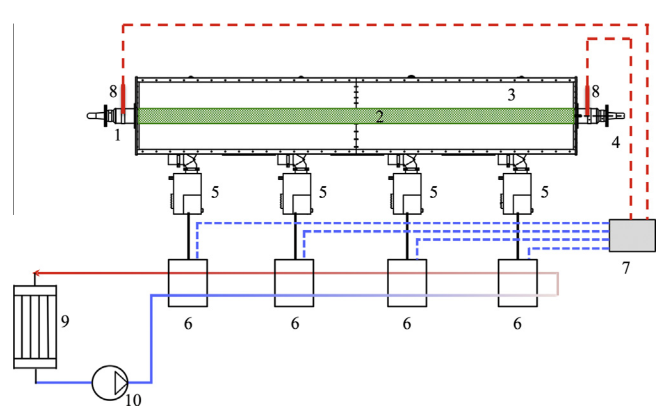

Fig. 1. Microwave prototype system: 1. Input; 2. PP tube; 3. Reverberant chamber; 4. Output; 5. Magnetron; 6. Power supply; 7. PLC; 8. Termocopule; 9. Water cooler; 10. Circulator.