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Pulsed electric field: groundbreaking technology for improving olive oil extraction

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Olive oil is a key component of the Mediterranean diet, and is recognized worldwide for its organoleptic and healthful properties. Extra virgin olive oil (EVOO) and virgin olive oil (VOO), the top categories according to world olive oil council standards, are only obtained by "cold" mechanical methods that preserve their characteristics. Industrial extraction of these premium olive oils basically involves three phases: (1) the crushing of the fruit to break plant tissues and release the oil, (2) the malaxation (slowly churning) of the milled olives to assist coalescence of the oil drops (typically at <27 °C, < 1h), and (3) the mechanical recovery of the oil by centrifugation (continuous mode; industrial process) or pressing (discontinuous mode; traditional-artisanal process). Afterwards, the olive oil is usually filtered or decanted to remove any possible solid residues, and finally bottled and marketed. While small mills process between 300 and 3,000 kg of olives per hour, the largest ones process up to about 12,000 kg of olives per hour and per each production line.

- **Pulsed electric field (PEF) has been proposed to increase olive oil extraction yields, while increasing the concentration of health-related molecules and consistently maintaining the highest oil quality.**
- **In some conditions, this technology would also allow the malaxation temperature to be reduced, preserving yields and potentially even improving sensory quality.**
- **Scaling up for industrial purposes is already possible, and the first pilot study at 520 kg/h has been conducted. The potential benefits of PEF are highlighted and quantified in this article.**

BIG OPPORTUNITIES TO IMPROVE YIELDS IN HIGH-QUALITY OLIVE OIL PRODUCTION

One of the most important industrial handicaps of VOO and EVOO production is the low efficiency of current mechanical extraction techniques. Although efficiency depends on the ripeness and variety of the olives and milling parameters (among other factors), typically only 80% of the oil present in the fruit is recovered by physical methods. The rest (20%) of the oil remains in the olive waste generated at the end of the process (Puértolas, *et al.,* http://dx.doi.org/10.1016/j.foodres.2015.12.009, 2016). Additionally, significant amounts of bioactive compounds like polyphenols are also lost with the olive waste. To recover as much oil as possible, the most widespread solution in oil mills is to increase malaxation time and/or temperature, or to run a second extraction cycle with the olive waste at high malaxation temperature. Such practices have a negative impact on chemical and sensory parameters, so the resulting olive oils are of low quality and category (neither EVOO nor VOO).

Pulsed electric field (PEF) is an emerging physical technology that has been largely studied for improving mass transfer processes in the food industry (Puértolas, *et al.,* http://dx.doi.org/10.1146/annurev-food-022811-101208, 2012). PEF pretreatment of crushed olives (olive paste) prior to centrifugation constitutes a great opportunity for improving extraction of VOO and EVOO, and increasing oil yield and bioactive compounds recovery—polyphenols recovery, for example (Puértolas, *et al.,* http://dx.doi.org/10.1016/j.foodchem.2014.07.029, 2015).

PULSED ELECTRIC FIELDS: FUNDAMENTALS AND KEY ASPECTS

PEF-assisted extraction essentially involves the discharge of direct current electric pulses of short duration (µs-ms) and high voltage (up to 50 kV) into a soft plant material located between at least one high-voltage electrode and one ground electrode (Puértolas, *et al.,* 2016). These electric pulses generate a pulsed electric field (typically up to 10 kV/cm), which produces the formation of pores in the cell membranes of plant tissues (Puértolas, *et al.,* 2012). This process, called electroporation, enhances the diffusion of solutes through the cell membranes, favoring the recovery of intracellular substances, including oil and molecules of interest. Furthermore, the application of electric fields has also been described *"per se"* as an effective demulsification technique, since electric fields facilitate coalescence processes and consequent separation of oil from water. Therefore, PEF could improve olive oil yields by a double mechanism: the improvement of oil extraction from olive tissue, and the releasing of olive oil trapped in vegetable oil-water emulsions. It is important to note that PEF is considered a "cold technology," as the conventionally used intensities do not cause a notable increase in the temperature (normally less than 5 °C). This is absolutely essential to preserve the valued organoleptic properties of the best olive oils (EVOO and VOO).

Fig. 1 summarizes the different stages of olive oil industrial production and the points where PEF has been proposed to be applied: (1) after malaxation, to facilitate the demulsification of the oil and also to improve mass transfer during the subsequent centrifugation, and (2) just after crushing. In this last case, PEF is mainly applied to enhance the subsequent release of oil during malaxation based on the electroporation of the cell membranes (Abenoza, *et al.,* http://dx.doi.org/10.1007/s11947-012-0817-6, 2013). Applying 30 minutes of malaxation at low temperature (15 °C), these authors achieved a 14.1% higher oil yield using PEF pretreatment (2 kV/cm), compared to the control process. Furthermore, the extraction yield was similar to that obtained for the control process at high temperature (26 °C). Therefore, PEF technology could help reduce maceration temperature from 26 to 15 °C, without affecting the extraction yield. Processing at this low temperature prevents the loss of volatile compounds which are essential for sensory quality, so the olive oil recovered by this innovative method could potentially present better organoleptic properties than those obtained using higher malaxation temperatures.

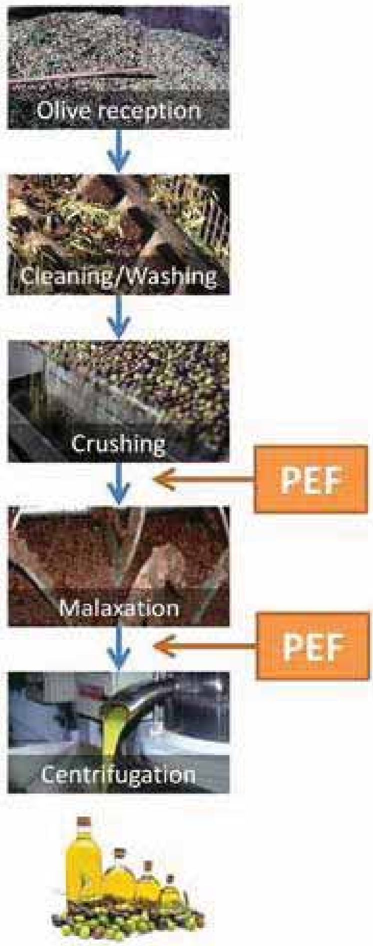

FIG. 1. Application of pulsed electric field (PEF) in the conventional production outline of olive oil

FIRST PILOT TRIAL: A SUCCESSFUL STORY

Recently, a pilot study in a small olive oil mill was conducted in Spain, demonstrating the potential of the technology at close to industrial scale (Puértolas *et al.,* 2015). A PEF unit designed and constructed by KEA-TEC (Waghäusel, Germany) was used to conduct the study. This PEF-unit included an in-line treatment chamber (tube configuration) specifically constructed to be easily incorporated into an olive oil production line. To conduct the trials, this treatment chamber was integrated into a continuous production plant (K30, Oleomio, Granada, Spain), just after the malaxation. This pilot system allowed 520 kg of olives to be processed per hour, applying electric fields of 2 kV/cm and 65 J (total specific energy applied: 11.25 kJ/kg).

In the control batch, the extraction yield was 20.0 kg of oil per 100 kg of processed olives; in the PEF-assisted extraction batch it was 22.7 kg/100kg. Based on these measurements, the PEF technology allowed us to improve the oil extraction yield by 13.3% compared to the control. Correspondingly, the PEF olive oil had higher concentrations of polyphenols, phytosterols, and total tocopherols than the control olive oil did (11.5%, 9.9%, and 15% higher, respectively). Chemical and sensory analysis showed that both control and PEF oils presented the highest quality according to the legal standards of the European Union, reaching the extra virgin olive oil (EVOO) category.

INDUSTRIAL FEASIBILITY, COST, AND POTENTIAL ECONOMIC BENEFITS

Although industry is not yet using PEF to improve vegetable oil recovery, the technology is being used commercially for other purposes. Full-scale PEF units are now operative in several food companies for other applications, such as replacing thermal blanching during potato snacks production or inactivating pathogen and spoilage microorganisms in juices and related products. Based on these applications, and taking into account the costs of electricity needed to improve oil recovery, the cost of an industrial PEF unit for this application could be estimated to be between $50,000 and $200,000, depending on the production rate. In addition, the electricity costs of the treatments would be about $0.33 per metric ton (MT) of processed olives (Puértolas, *et al.,* 2016).

In VOO and EVOO production without PEF, approximately 4 kg of oil per each 100kg of processed olives remain in the olive waste, resulting in a great monetary loss for the olive oil producers. According to the results obtained in the pilot trials, a PEF treatment could potentially help recover 50% of this residual oil. In an industrial oil mill operating at 10,000 kg/h (16h/day), a PEF treatment could potentially increase the VOO/EVOO daily production to 4,326 kg (from 32,000 to 36,320 kg). Assuming a VOO/EVOO price of $3–$6 per kg (according to pricing data from the International Olive Council), these figures mean a potential extra turnover of between $12,978 and $25,956 per production day. This would easily offset the electricity cost of the treatments ($0.33/MT) and pay back the capital cost of the PEF unit in a short time. Moreover, the potential increase in the concentration or bioactive compounds, such as polyphenols or phytosterols, could have also have a positive impact on the final oil price. In any case, more pilot and pre-industrial trials and precise economic studies should be conducted to obtain more data at near to industrial levels.

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