Chapter

Impact of PEF (Pulsed Electric Fields) on Olive Oil Yield and Quality

Oleksii Parniakov, Sam David Hopper and Stefan Toepfl

Abstract

Olive oil holds significant importance in the European diet and is renowned globally for its sensory attributes and health benefits. The effectiveness of producing olive oil is greatly influenced by factors like the maturity and type of olives used, as well as the milling techniques employed. Generally, mechanical methods can extract approximately 80% of the oil contained in the olives. The rest 20% of the oil remains in the olive waste generated at the end of the process. Additionally, significant amounts of bioactive compounds like polyphenols are also lost in the olive pomace. Traditionally, heat treatment, enzymes, and other chemicals are used for the enhancement of oil extraction; however, this approach may impact the quality of olive oil. Therefore, new technology, such as pulsed electric field (PEF), is of great benefit for nonthermal yield and quality improvements.

Keywords: electroporation, olives, EVOO, extraction, PEF, bioactives

1. Introduction

The International Olive Council reports that olive oil production on a global scale has tripled over the past 60 years. For the 2021/22 crop year, it is estimated that production reached 3,098,500 tons [1].

Virgin olive oil (VOO) and especially extra virgin olive oil (EVOO) is considered as a main part of the Mediterranean diet. Furthermore, thanks to its rich content of bioactive compounds like phenols, biophenols, phytosterols, and tocopherols, regular consumption of olive oil enhances antioxidant levels and improves blood lipid profiles, thus lowering the risk of certain degenerative diseases like atherosclerosis and cancer [2]. The extraction of VOO and EVOO consists only of mechanical processes. According to the EU Regulation EC 1513/2001 [3], olive oil should consist only of the following steps: (i) the crushing of olives to break the plant tissues, facilitating the release of oil, (ii) the process of malaxation applied to the olive paste to encourage the coalescence of oil droplets, the temperature of olive paste at this stage should not exceed 27°C and usually done for around 1 h, and (iii) the mechanical recovery of the oil by decantation/centrifugation or pressing. Afterward, obtained oil/water mixture goes through speed separation and lately filtered or decanted to remove any possible, solid residues prior to bottling.

The efficiency of traditional EVOO and VOO production is relatively low, resulting in around 20% of oil losses. There are two main sources of such high losses: (i) oil remains inside the olive cells or (ii) it is emulsified with water. Those losses could be connected to the way and conditions of extraction or/and olives variety. Traditionally, thermal treatments or the addition of technological coadjuvants (talc, calcium carbonate, enzymes) have been used to improve the oil extraction from olives [4]. It is well known that a temperature rise reduces the viscosity of oil and improves its diffusivity, thus enhancing oil yield. However, olive oil obtained at temperatures higher than 27°C cannot be named EVOO. High temperatures also destroy thermosensitive compounds, such as phenols and aromatic compounds, that directly impact the organoleptic properties of oil. The usage of technological coadjuvants, in general, improves the oil yield and oil quality. For example, the usage on enzymes such as cellulases, hemicellulases, and pectinases can increase the oil yield by 1–2%. The level of the effect depends on the cultivar and olive fruit maturity [5]. Moreover, their use can increase the concentration of phenolic compounds in the paste and oil [6]. However, the purchase price of such adjuvants is quite high, in the range of 30–50 €/L.

Nowadays, emerging nonthermal technologies such as pulsed electric fields (PEF) and ultrasound are gaining more and more interest in food science and technology.

Pulsed electric fields (PEF) consist of the application of high voltage (1–30 kV) and short pulses (ns-μs) to the food products. The PEF is based on the mechanism of electroporation that, due to the electrocompression forces, induces the pores of different shapes and diameters on the cell membrane, hence improving mass and heat transfer processes. Therefore, the combination of conventional malaxation with PEF generally improves extraction efficiency and release of bioactive compounds. Moreover, its application can lead to improved nutritional and sensory quality of EVOO.

The increase in olive oil yield due to PEF (pulsed electric field) can be attributed to two factors: (i) the enhancement of oil extraction from olive tissue and (ii) the liberation of olive oil that was previously trapped in oil/water emulsion [7]. The first one could be explained by the electroporation of the cytoplasmic membranes that results in the improvement of mass transfer processes through cell envelopes [8, 9]. Therefore, PEF assists in the release of oil from lipo-vacuoles of mesocarp cells that have not been disrupted by crushing [10]. However, some part of oil is emulsified with water, and subsequently, it is lost with olive pomace after decantation process [11]. The main difficulty of freeing this bound oil is connected to the fact that droplets of emulsified oil are surrounded by a lipoprotein membrane [12]. Nevertheless, some authors hypothesized that the PEF treatment could have disrupted the lipoprotein membranes, thereby facilitating the release of oil [8].

Different research groups have investigated the influence of PEF on olive oil yield in the lab, pilot, and industrial scale [8, 13–15]. They have found that the olive oil yield can be enhanced by up to 15% with application of PEF. Moreover, the increase of the concentration of bioactive compounds such as polyphenols, phytosterols, and total tocopherols by 11.5, 9.9, and 15%, respectively, in oil extracted from PEF-treated olives can be achieved [8].

This chapter will discuss the effect of PEF treatment on plant tissue. Furthermore, a deep dive into the benefits of PEF application in the production of olive oil will be discussed. The process and quality benefits will be presented.

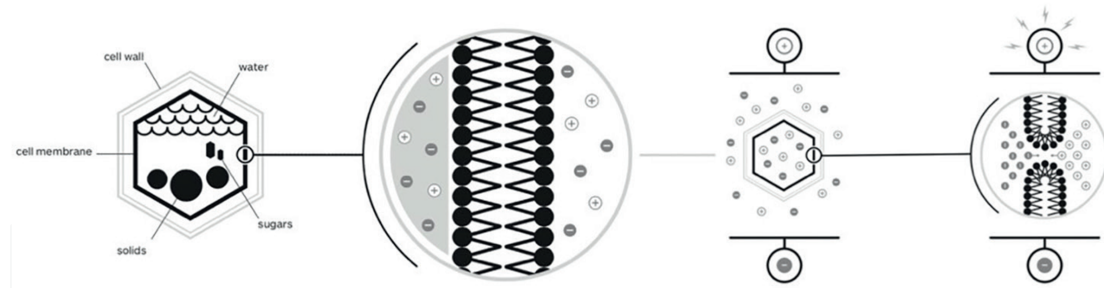

Figure 1.
Schematic representation of cell electroporation.

2. Action of PEF

PEF is based on mechanism of electroporation, and this phenomenon has been intensively researched for several decades in the scope of microbial inactivation and mass transfer enhancement [16, 17].

The applied electric field causes a dielectric breakdown of the membrane and thus influences the membrane structure and increases its permeability [18]. The electroporation process can be divided into four main steps [19]. Due to its nature biological cell membrane is considered as a capacitator filled with dielectric material of low electrical conductivity [17]. A cell membrane consists of phospholipid bilayer; therefore, it has a natural transmembrane potential, referring to the voltage difference by intra- and extracellular ionic concentrations [20]. Firstly, the electric field applied to the food product causes polarization of the cell membrane, leading to an increase in the transmembrane potential [21]. Secondly, hydrophilic pores are formed in the membrane. This pore formation stage can be explained by the electromechanical model, which is the most common one [21]. When the applied electric field surpasses a specific critical threshold, electrocompression forces emerge on both sides of the membrane, leading to the deformation and instability of the cell membrane (**Figure 1**).

Thirdly, the number and size of the pores increases with the duration of the electric pulse [21]. Depending on the intensity of the applied electric field, thickness of the membrane, cell shape, and size, electroporation can be reversible or irreversible. Usually, exceeding the critical electric field strength between 1 and 2 kV/cm induces irreversible pores in plant cells [22].

3. EVOO oil yield increase

Typical layout of the olive oil mill is presented in **Figure 2**. Usually, production of EVOO consists of crushing, malaxing, solid/liquid, and liquid/liquid separations.

PEF system is usually installed after the crasher to enhance the subsequent release of oil during malaxation based on the electroporation of the cell membranes. However, it can be implemented in some cases after the malaxation step to facilitate the demulsification of the oil and to improve mass transfer during the subsequent mechanical separation. Application of PEF in olive oil production has been intensively researched by different scientific groups at lab, pilot, and industrial scales [8, 13, 14]. Example of PEF industrial installation after crusher is presented in **Figure 3**. Here, 30 kW PEF system from Elea Technology GmbH has been used for treatment of 12 t/h of olive paste.

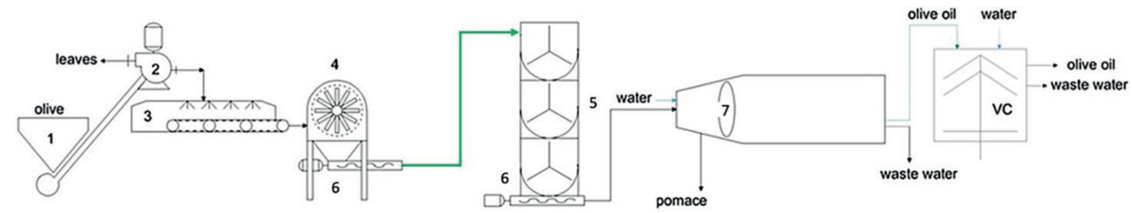

Figure 2.
Typical layout of the olive oil mill. Here, 1 is a loading hopper; 2 is a defoliator; 3 is a washing machine; 4 is a crusher machine; 5 is a malaxer; 6 is cavity pump stators; 7 is a solid/liquid horizontal centrifugal decanter. Adopted from [13].

Figure 3.
Industrial PEF installation. Own unpublished picture.

Research conducted at laboratory and industrial scales has demonstrated that the PEF treatment of the olives results in enhancement of oil extraction without negative impact on sensorial attributes while maintaining the EU legal standards for the highest quality EVOO [7].

The first studies on application of PEF on lab scale have indicated that application of this technology can increase the yield of olive oil by up to 7.4% (**Figure 4**) [15].

Research study conducted by [8] has mentioned that PEF treatment of olive fruits (Arroniz variety) resulted in increase of extraction yield by 2.7% mass compare to traditional method of extraction. Similar results have been obtained by application of PEF treatments to the olive paste from different olives varieties (Nocellara del Belice). It has been stated that positive effect on extractability was achieved after application of PEF treatment at 2 kV/cm and 7.83 kJ/kg. In fact, the yield has been increased by 6% when a PEF system was used. The authors stated that the PEF treatment of olive paste resulted in a significant reduction of oil loss in pomace of about 40.5% [23]. Furthermore, three different varieties of olive fruits (Tsounati, Amfissis, and Manaki variety) were subjected to PEF conditions ranging from 1.6 to 70.0 kJ/kg before being subjected to malaxation for 30 minutes at 30°C. As a result of this PEF treatment, the extraction yield of olive paste was boosted by up to 18 times compared

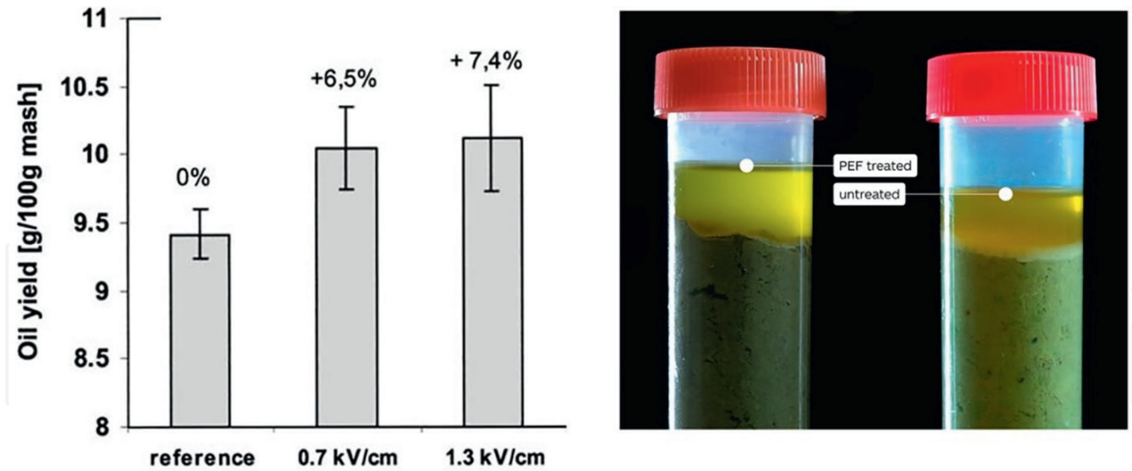

Figure 4.
Yield of oil from PEF-treated and untreated olive paste. Adopted from [15] and visual representation of oil yield increase.

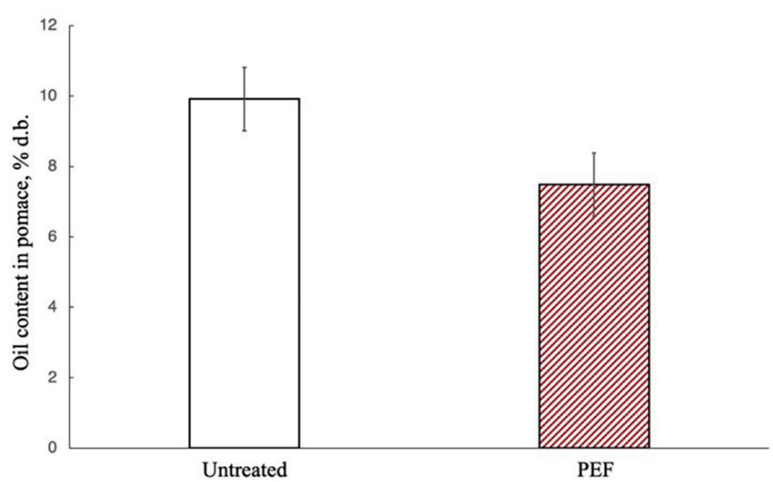

Figure 5.
Oil content in the untreated and PEF-treated olive pomace after solid/liquid separation. Adopted from [13].

to the untreated samples [24]. A recent study has shown that the pomace samples treated with PEF have a significantly lower content of residual olive oil than untreated samples (**Figure 5**). The authors stated that the extraction of olive oil has been significantly enhanced by more than 3% [13].

Additionally, to the enhancement of EVOO extraction, the reduction of malaxation time and temperature has been observed. It has been demonstrated that PEF implantation and malaxation at a low temperature of 15°C for only 30 min can increase oil yield by 3%, compared to the traditional thermal process at 26°C. It is worth mentioning that extraction at such low temperature reduces losses of volatile and bioactive compounds, which are important for the sensory quality of olive oil [14]. However, a more recent study, where the extraction efficiency has been evaluated for untreated and PEF-treated olive paste at different malaxation time, stated that there is a certain optimum time when maximal oil yield can be achieved. The authors found that for PEF-treated samples, 30 min of malaxation time was enough to reach maxima yield (**Figure 6**). At this time, an extra yield of 1.9 ± 0.3% was obtained for PEF samples compared to the untreated one. However, when a longer time of malaxation was used, these yield differences were reduced [25].

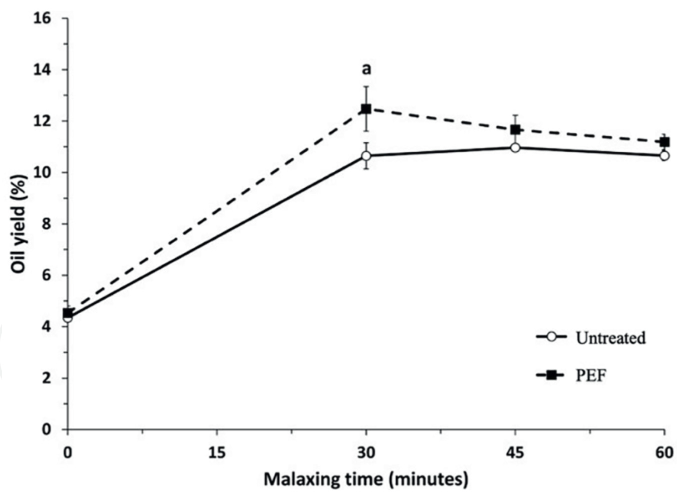

Figure 6.
Yield of oil from untreated and PEF-treated olive paste malaxed at different temperature [25].

4. Quality of PEF-extracted olive oil

EVOO is characterized by the high content of various bioactive compounds such as biophenols, tocopherols, and phytosterols [26]. The principal group of antioxidants in EVOO is hydrophilic phenols. These compounds are extremely important cause they determine the sensory characteristics, like bitterness, pungency, and stability of the oil [27], as well as determining the aroma and flavor of EVOO. The majority of bioactive compounds are thermosensitive, and their concentration in the final oil depends on many factors such as variety of fruits, harvesting time, process conditions, etc., [28]. Additionally, to increase oil yield PEF also improves the extraction of bioactive compounds from the olive paste. One research group has demonstrated that the concentration of bioactive compounds such as polyphenols, phytosterols, and total tocopherols in oil extracted from PEF-treated olives was higher compared to traditionally extracted one by 11.5, 9.9, and 15%, respectively [8]. In the traditional extraction process, the total tocopherol concentration in the oil was measured at 19.2 mg/100 g. However, with the application of pulsed electric field (PEF), there was a significant increase in tocopherol content by 15.0%, reaching a value of 22.0 mg/100 g. Notably, when comparing individual isomers in both traditional and PEF-extracted oils, only a-tocopherol showed a significant difference, with its value increasing by 25%, from 11.4 mg/100 g to 14.3 mg/100 g, respectively [8]. Another researcher found a slight increase of a-tocopherol as well in oil extracted from PEF-treated Arbequina olive pomace (1.67%) [14]. It was found an increase of total phenolic compounds (TPC), oleacein, and 3,4-DHPEA-EA in the oil obtained from the PEF-treated olive paste in the last phase of malaxation could probably be linked to enhanced PC release and solubilization [29]. Other researchers have also reported higher levels of phenolic compounds and oleuropein derivatives, particularly 3,4-DHPEA-EDA, in comparison to the control extra virgin olive oil (EVOO). However, there were no significant differences observed in the content of other phenolic compounds like secoiridoid derivatives (especially ligstroside), lignans, and α-tocopherol [13]. It has been noted that the enhanced extraction capability of this process justifies the energy requirements, making Pulsed Electric Field (PEF) technology a promising method for extracting oil from the olive paste matrix, with positive effects on the quality of the final products. Moreover, a slightly higher content of dialdehydic forms of decarboxymethyl elenolic acid linked to hydroxytyrosol (3,4-DHPEA-EDA or oleacein) and to tyrosol (p-HPEA-EDA or oleocanthal) was observed in EVOO extracted from Nocellara del Belice variety of olives using PEF technology compared to the control test [23].

Organoleptic properties of olive oil have high importance for the final consumers. Several studies have shown that PEF EVOO has a slightly higher bitterness compared to traditionally extracted. These findings can be explained by a generally higher content of polyphenols in the PEF EVOO. However, two other parameters such as fruitiness and spiciness are not affected by PEF [13].

One of the research groups was investigating the shelf-life of PEF and control EVOO. The tests suggest that the quality of oil derived from nonthermally pretreated olives is influenced by the chosen technology and process conditions. Notably, the application of pulsed electric field (PEF) treatment has shown to result in an increase in the oxidative stability of the oil obtained from these olives [24].

5. Conclusions

PEF treatment is one of the most promising emerging technologies. Numerous research groups have been investigating the effect of PEF on production of olive oil. It has been found that the application of PEF to the olive pomace prior to malaxation leads to various process and product benefits. It was demonstrated that oil could be easier extracted from PEF-treated olive paste. In general, the oil yield increase has been found in the range of 3–15%. Such a high range of yield increase might be connected to different olives varieties, harvesting conditions, and time, as well as processing parameters, mainly malaxation time and temperature. What is more, PEF can reduce the malaxation time by up to 30 min. This process benefit would help oil producers to increase their production capacities with relatively low investments and small footprints. It is well known that PEF increases the diffusion coefficient; moreover, the lower the process temperature is, the bigger this increase. Meaning, in the possibility of reducing the malaxation temperature that would lead to lower energy consumption and higher quality of the final product. Finally, PEF increases the extraction of health-promoting compounds such as phenols, tocopherols, etc., resulting in healthier and more premium EVOO. Overall, it has been demonstrated that PEF treatment can be a perfect substitution for any type of used adjuvant (talc, enzymes, etc.). In the long run, implementation of PEF technology in the olive mill would remove the running costs connected to the costs of technological adjuvants and would open the possibility of increasing production capacities without a substantial capital investment.

Apart from technological advantages, implementation of PEF brings along extra monetary benefits. According to the aforementioned results the implementation of PEF treatment has the potential to raise the oil yield from 20% to 22.7%. In an industrial oil mill processing 160 tons of olives per day, the application of PEF treatment could increase the daily production of extra virgin olive oil (EVOO) by 4.33 tons, resulting in a totals output of 36.33 tons per day, up from the original 32 tons. According to the International Olive Council, the EVOO price in 2022 were between 2 and 3.7 €/kg [30], which would result in a potential extra turnover of between 8660 € and 16,021 € per production day. Additionally, the possible rise in the concentration of bioactive compounds, such as polyphenols or phytosterols, could positively influence the final price of the oil.

Conflict of interest

The authors declare no conflict of interest.

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