Chapter

Emerging Extraction Technologies in Olive Oil Production

Alev Yüksel Aydar

Abstract

In the field of olive oil extraction, current scientific research has focused on improving quality, paying particular attention to optimizing the efficiency of extraction and reducing the duration of the process. Recently, studies have been conducted to improve the traditional malaxation process and obtain positive effects on both oil production and consumption. With these aims, emerging technologies including microwave (MW), pulsed electric field (PEF), and ultrasound (US) have been applied to conventional virgin olive oil extraction process. In this chapter, most recent studies that focused on adaptation of emerging technologies to traditional extraction to increase the yield of olive oil or some minor compounds and bioactive components present in olive oil including tocopherols, chlorophyll, carotenoids, and phenolic compounds have been compiled.

Keywords: novel technologies, olive oil, extraction, ultrasound, microwave

1. Introduction

The conventional extra virgin olive oil (EVOO) extraction method consists of three main processes, which are crushing, malaxation, and centrifugation [1]. After washing olive fruits, they are crushed using a stone-mill, hammers, disc crushers, de-stoning machines, or blades [2]. The purpose of this step is to facilitate the release of the oil droplets from the Elaioplasts. The minimum size for the continuous separation process of olive oil is 30 μm, but only 45% of the oil droplets have a diameter greater than 30 μm after crushing increases. This ratio reaches 80% with the formation of larger diameter drops from the oil droplets by malaxation [3]. Malaxation and crushing are main steps that affect the quality and yield of oil [4]. A flow chart of extra virgin olive oil extraction is shown in Figure 1.

Conventional techniques in olive oil extraction have not changed significantly for last 20 years [5]. However, in line with research findings and new techniques developed by market demand, the ongoing food industry has become very active in looking for new methods for food innovation. But, it is still very uncommon for the food industry to develop and adopt advanced processing techniques in the direction of consumers’ increasing food safety and quality requirements [6]. Researchers working on the development of food technology are making great efforts to develop and implement “minimal processing” strategies to remove the negative effects of traditional food processing methods. The most general definition of minimal processing can be: preserving the nutritional quality and sensory qualities of food by heat application, which is the basic protection step in food processing, for a shorter
Technological Innovation in the Olive Oil Production Chain

Emerging technologies including microwave, high-pressure processing, pulsed light, radio frequency, Ohmic heating, ultrasound, and pulsed electric field (PEF) are widely applied emerging minimal processes in the food industry.

In recent years, novel technologies such as ultrasound, pulsed electric field, or microwave have been adopted in olive oil extraction [1, 8–10] because of their positive effects including enhanced extraction efficiency, reduced extraction time, increased yield, and low energy consumption.

Ultrasound is one of the main emerging technologies widely used in various extraction processes of plant materials [11, 12]. In order to enhance oil extraction, ultrasound can be applied to the olive paste due to its mechanic effect on the cell membranes, which induces them to release oil easily from vacuoles with a considerably lower malaxation time and higher oil quality and yield [2, 5, 10, 13–18]. In addition to the extraction process, ultrasound was also investigated in numerous studies on food processing methods including emulsification, filtration, crystallization, inactivation of enzymes and microorganisms, thawing, and freezing on foods [19, 20].

It has been demonstrated that pulsed electric field (PEF), another non-thermal technology, is effective for reversible or irreversible permeabilization of cell membranes in several plant tissues, without significant temperature increase [8]. PEF technology, which has been used in the field of food science since 1960, is based on the principle of exposing liquid or solid food products to an electric field causing pores in cell membranes [6].

Microwave-assisted extraction (MAE) is an alternative oil extraction method in recent years. Since microwave provides more rapid heating and destruction of biological cell structures in a shorter time, it is a more efficient extraction method than
conventional processes. Other important advantages of this method are obtaining high-quality oil and low energy requirement, which cause a significant reduction in environmental impact and financial costs [21].

More emphasis has been placed on the understanding of a superior EVOO quality based on the preservation of the sensory characteristics and positive health properties of olive oil in recent years. This aspect of EVOO quality is strongly related to the presence of phenolic and volatile compounds [13, 22]. Therefore, utilization of an emerging technology in olive oil extraction should not only increase oil yield, but also protect and improve the bioactive oil compounds and the oil quality. Recent studies that applied emerging technologies to olive oil extraction are summarized in Table 1.

| Variety of olive | Emerging technology* | Investigated parameters | Dependent variables | Refs. |
|-----------------|----------------------|-------------------------|---------------------|-------|
| Edremit          | HPU                  | Ultrasound time, ultrasound temperature, malaxation time | Oil yield, acidity, peroxide value, and antioxidant properties | [1] |
| Coratina         | HPU                  | Ultrasound application step (After crushing/before crushing) | Olive paste temperature, energy balance, oil yield, quality indices of oil, minor compounds | [10] |
| Picual           | HPU                  | Direct/indirect application of ultrasound | Olive paste temperature | [15] |
| Picual           | HPU                  | Continuous ultrasound application before centrifugation | Oil yield, quality indices, volatile and minor compounds, fatty acid composition | [23] |
| Edremit, Gemlik, Uslu | HPU                  | Ultrasound and malaxation time | Oil yield, UV absorbance values, acidity, peroxide value, total phenolic content | [24] |
| Picual           | HPU                  | Olive paste flow, HPU intensity, fruit temperature, olive moisture, and fat content | Olive paste temperature | [25] |
| Oglarola Barese  | HPU, MW              | Thermal effect of US and MW | Malaxation time, oil yield, quality characteristics, and energy efficiency | [14] |
| Arbequina        | PEF                  | Malaxation time and temperature, electric field strength (kV/cm) | Oil yield, acidity, quality characteristics, total and individual phenols | [8] |
| Arroniz          | PEF                  | Application of PEF | Oil yield, acidity, quality characteristics, total phenols, sensory properties | [9] |
| Unspecified/Olive pomace used | MW                  | Microwave power, irradiation time, solvent-to-sample ratio | Oil yield, physicochemical oil properties | [26] |
2. Ultrasound applications in olive oil extraction

In the olive oil industry, ultrasound is one of the most promising technologies because of its powerful mechanical and mild thermal effects [32]. Many researchers have used this technology to investigate its effects on overall olive oil quality and yield in the last decade [1, 10, 14–16, 23–25, 33]. In recent years, it has been discovered that using a stronger ultrasound (>1 W/cm²) at a lower frequency (generally around 20–50 kHz), which is also called high-power ultrasound (HPU) (usually around 20–50 kHz), is physically effective in altering the properties of a substance or inactivating microorganisms [6, 7].

High-power ultrasound application in olive oil extraction was first performed by Jiménez et al. [15] under discontinuous conditions. In their studies investigating the effects of direct and indirect ultrasound, they found that direct sonication provided better extractability in high-moisture olives (>50%) while greater extractability was obtained by indirect sonication in low-moisture olive fruits (<50%) [15].

Enrichment of olive oil with main phenols in olive leaves using ultrasound has been studied by researchers [34, 35]. Achat et al. [34] used ultrasound to enrich olive oil with oleuropein both on a laboratory and a pilot plant scale. The ultrasound-assisted extraction method greatly facilitated the enrichment of VOO in phenolic compounds compared to conventional processes. They found that tyrosol and hydroxytyrosol, main phenolic compounds present in olive oil, were not significantly degraded by sonication [34].

Clodoveo et al. [10] investigated ultrasound application on olive fruits submerged in a water bath before crushing and also on olive paste after crushing. The purpose of their study was to test the possibility of decreasing the malaxation time. Reduction in the malaxation time and improvement in oil yields and its minor nutritional compounds were attained by ultrasound technology. The results were better in oils obtained by sonication of olives in water bath than those obtained by sonication of olive paste [10].

Bejaoui et al. [25] applied HPU to olive paste through the pipe before centrifugation with continuous conditions. They observed that when the oils were extracted

---

| Variety of olive | Emerging technology* | Investigated parameters | Dependent variables | Refs. |
|-----------------|----------------------|-------------------------|--------------------|-------|
| Chemlal         | MW                   | The extraction time, acetic acid content in hexane, irradiation power | Oil yield, total phenols, quality parameters | [27] |
| Unspecified/Olive oil used | MW | Microwave heating times | Quality and physicochemical properties, oil color | [28] |
| Coratina        | MW/MS                | MW and MS combined effect | Rheological properties, oil yield | [29] |
| Peranzana       | MW                   | Malaxation time and MW | Energy consumption, oil yield, structure modifications of olive pastes | [30] |
| Coratina        | HPU                  | Sonication time         | Oil yield, oil quality indices, phenolic composition | [31] |

*HPU: High-power ultrasound, PEF: Pulsed electric field, MS: Megasonic treatment, MW: Microwave.

Table 1. Emerging extraction technologies used in olive oil production.
without ultrasound, the extraction yield was 46.83% ± 0.83, while ultrasound treatment of olive paste produced a significant increase in extraction yields to 52.75% ± 1.39.

Aydar et al. [1] used an ultrasound bath in olive oil extraction to find optimum ultrasound-assisted olive oil extraction conditions based on maximum oil yield and minimum free acidity. The acidity of the oils for all experiments was below the legal limit (<8 g oleic acid/kg oil) established for the category of EVOO [36]. The most important impact on the extraction yield and the acidity (p < 0.05) was due to the malaxation temperature. They also observed that ultrasound time had no significant effect (p > 0.05) on the acidity and yield [36].

The effect of malaxation time combined with the use of ultrasound on the oil yield, oxidative and quality characteristics of EVOOs extracted from different Turkish olive cultivars was studied by Aydar [24]. It was found that different sonication and malaxation time combinations did not cause difference (p > 0.05) in the Edremit oil yield and extractability indexes, while they were significantly different in Uslu and Gemlik oils. In that study, oils obtained by 8 min of ultrasound application and 22 min of malaxation had highest oil yield and chlorophyll and carotenoid contents. [24]

3. PEF applications in olive oil extraction

Olive paste was exposed to PEF technology involving 50 monopolar pulses of 3 μs at an electric field strength of 1 kV/cm (1.47 kJ/kg) and 2 kV/cm (5.22 kJ/kg) and a frequency of 125 Hz. PEF did not result in any significant differences in fatty acid composition and sensorial properties of oil. In sensorial properties point, panelists evaluated the oil subjected to PEF was less bitter and pungent, and more fruity than the untreated oils. The PEF treatment was very effective to increase the oil yield when combined with malaxation. The oil yield as was high as 14.10% when the olive paste was subjected to PEF at 2 kV/cm and malaxed for 30 min at 15°C. However, the extraction yield was reduced by 50% when no malaxation was applied to olive paste compared to those malaxed for 30 min. [8]

Effect of the use of pulsed electric field (PEF) technology on Arroniz olive oil production in terms of extraction yield and chemical and sensory quality has been evaluated by Puértolas and Marañón [9]. Extraction yield increased by 13.3% in PEF-treated samples (2 kV/cm, 11.25 kJ/kg) compared to control. In addition, the total phenolic content, total phytosterol, and total tocopherol of olive oil extracted with PEF showed significantly higher values (11.5, 9.9, and 15.0%, respectively) than the control group. [9]

4. Microwave applications in olive oil extraction

Over the last few decades, microwave treatments in food processing have gained popularity because of their low heat treatment times, operational simplicity, and high heating rates, which result in lower maintenance requirements. The microwaves obtained from household ovens and many industrial applications are produced efficiently by permanent wave magnetrons (Figure 2) [6].

The effect of heating with microwave and its comparison with conventional heating and ultrasound heating on crushed olives was investigated by Clodoveo and Hbaieb [14]. Results showed that the main quality parameters legally established (acidity, peroxide value, and specific extinction coefficients (K232 and K270)) to evaluate VOO were not affected by the microwave and ultrasound treatments. Moreover, the malaxation time was decreased and extraction yield was improved by
ultrasound and microwave treatments compared with the oils that were extracted from the olive paste without malaxation. [14].

Yanik et al. investigated microwave-assisted solvent extraction (MASE) parameters on olive pomace oil. The yield of oil obtained by conventional extraction was lower than that of oil obtained by microwave extraction from olive pomace. It demonstrated that microwave-extracted oils had higher total phenolic (985 mg caffeic acid/kg oil) and tocopherol compounds (278.07 mg/kg oil), also lower peroxide value (178 meq O₂/kg oil) and polycyclic aromatic hydrocarbons (PAH) (0.44 μg benzo(α) pyrene/kg) compared to oils extracted by conventional industrial methods. [26]

The effect of microwave-assisted solvent extraction at two different radiation power values (170 and 510 W) combined with acetic acid on yield and physicochemical properties of olive oil was studied by Kadi et al. [27]. The UV absorbance values were highest in oils treated with 510-W microwave and 7.5% acetic acid content. Since microwave radiations accelerate the disruption of cells and oil release, they observed similar results to those of previous researchers who also achieved better oil extractability [27].

Malheiro et al. determined the effect of different microwave heating times (1, 3, 5, 10, and 15 min) on three Portuguese olive oils of different origins, one from the north, “Azeite de Trás-os-Montes” protected designation of origin (PDO); one from the center, “Azeites da Beira Interior” PDO; and one from the south of Portugal, “Azeite de Moura”. They evaluated the effect of MW time on free acidity; peroxide value (PV); specific extinction coefficients (K232 and K270); color; and chlorophyll, carotenoid, and tocopherol content of oils. The carotenoids and chlorophyll pigments, which are also significant in determining olive oil stability, decreased by microwave treatment [28].

Leone et al. [30] determined the effect of microwave treatment on oil yield, structure modifications of olive pastes, and total energy consumption for a whole extraction process. The oil extractability was not significantly different from traditional extraction; however, the electrical power consumption using a microwave prototype system was higher by 24% [30].

The possibility of combining megasonic and microwave treatment in a continuous olive oil extraction system to enhance olive oil extractability was examined by Leone et al. [29]. The utilization of combined megasonic and microwave treatment to olive paste resulted in a consistent reduction of viscosity. In result, both microwave and megasonic technologies have improved the oil extractability performance by lowering the consistency of the olive paste [29].

In recent years, infrared spectroscopy, computer vision, machine olfaction technology, electronic tongues, and dielectric spectroscopy are some of the main
sensing technologies applied to the virgin olive oil production process. Infrared spectroscopy can also be used to evaluate the official quality parameters of olive fruits and oil [37].

5. Conclusions

Worldwide, the total consumption of olive oil increased from 1,666,500 tons in 1990/1991 to 2,978,000 tons in the period of 2017/2018 after 27 years [30]. Recent studies on emerging extraction techniques aim to improve the quality and physicochemical properties of oils and reduce the processing time and energy consumed during extraction compared to traditional methods. Ultrasound, microwave, and pulsed electric field technologies have been successfully applied to olive oil extraction, and several positive impacts on oil yield and quality have been observed. Results show combining these emerging technologies could assist in the development of a continuous olive oil extraction process with a higher extractability than the traditional batch process without significant decrease in oil quality. Long-term stability and sensory studies should also be done to evaluate the long-term effects of these new technologies and to ensure their advantages.

Conflict of interest

The author declares that she has no “conflict of interest.”

Author details

Alev Yüksel Aydar
Department of Food Engineering, Faculty of Engineering, Manisa Celal Bayar University, Manisa, Turkey

*Address all correspondence to: alevyuksel.aydar@cbu.edu.tr
References

[1] Aydar AY, Bagdatlioglu N, Köseoglu O. Effect of ultrasound on olive oil extraction and optimization of ultrasound-assisted extraction of extra virgin olive oil by response surface methodology (RSM). Grasas y Aceites. 2017;68:1-11 [Epub ahead of print]. DOI: 10.3989/gya.1057162

[2] Veneziani G, Sordini B, Taticchi A, Esposto S, Selvaggini R, Urbani S, Di Maio I, Servili M. Improvement of Olive Oil Mechanical Extraction: New Technologies, Process Efficiency, and Extra Virgin Olive Oil Quality. Products from Olive Tree Dimitrios Boskou and Maria Lisa Clodoveo. IntechOpen. 2016. DOI: 10.5772/64796. Available from: https://www.intechopen.com/books/products-from-olive-tree/improvement-of-olive-oil-mechanical-extraction-new-technologies-process-efficiency-and-extra-virgin

[3] Boskou D. Olive oil, Chemistry and Technology. Thessaloniki, Greece: AOCs; 2006. [Epub ahead of print]. DOI: 10.1159/000097916

[4] Clodoveo ML, Hbaieb RH, Kotti F, et al. Mechanical strategies to increase nutritional and sensory quality of virgin olive oil by modulating the endogenous enzyme activities. Comprehensive Reviews in Food Science and Food Safety. 2014;13:135-154

[5] Clodoveo ML. An overview of emerging techniques in virgin olive oil extraction process: Strategies in the development of innovative plants. Journal of Agricultural Engineering. 2013;44:49-59 [Epub ahead of print]. DOI: 10.4081/jae.2013.s2.e60

[6] Sun D-W. Emerging Technologies for Food Processing. 2nd ed. Dublin: Elsevier Inc.; 2014

[7] Baysal T, İçler F. Gıda Mühendisliği’nde Islı Olmayan Teknolojiler. Bornova, İzmir: Nobel yayincilik; 2012

[8] Abenoza M, Benito M, Saldaña G, et al. Effects of pulsed electric field on yield extraction and quality of olive oil. Food and Bioprocess Technology. 2013;6:1367-1373

[9] Puértolas E, Martínez de Marañón I. Olive oil pilot-production assisted by pulsed electric field: Impact on extraction yield, chemical parameters and sensory properties. Food Chemistry. 2015;167:497-502

[10] Clodoveo ML, Durante V, La Notte D. Working towards the development of innovative ultrasound equipment for the extraction of virgin olive oil. Ultrasonics Sonochemistry. 2013;20:1261-1270

[11] Aydar AY. Utilization of Response Surface Methodology in Optimization of Extraction of Plant Materials. United Kingdom: Intech Open; 2018. pp. 157-169

[12] Amirante R, Distaso E, Tamburrano P, et al. Acoustic cavitation by means ultrasounds in the extra virgin olive oil extraction process. Energy Procedia. 2017;126:82-90

[13] Clodoveo ML. New advances in the development of innovative virgin olive oil extraction plants: Looking back to see the future. Food Research International. 2013;54:726-729

[14] Clodoveo ML, Hachicha Hbaieb R. Beyond the traditional virgin olive oil extraction systems: Searching innovative and sustainable plant engineering solutions. Food Research International. 2013;54:1926-1933

[15] Jiménez A, Beltrán G, Uceda M. High-power ultrasound in olive paste pretreatment. Effect on process yield and virgin olive oil characteristics. Ultrasonics Sonochemistry. 2007;14:725-731
[16] Clodoveo ML, Durante V, La Notte D, et al. Ultrasound-assisted extraction of virgin olive oil to improve the process efficiency. European Journal of Lipid Science and Technology. 2013;115:1062-1069

[17] Clodoveo ML, Camposeo S, Amirante R, et al. Research and Innovative Approaches to Obtain Virgin Olive Oils with a Higher Level of Bioactive Constituents. AOCS Press. 2015. [Epub ahead of print]. DOI: 10.1016/B978-1-63067-041-2.50013-6

[18] Clodoveo ML, Dipalmo T, Schiano C, et al. What’s now, what’s new and what’s next in virgin olive oil elaboration systems? A perspective on current knowledge and future trends. Journal of Agricultural Engineering. 2014;45

[19] Bermúdez-aguirre D, Mobbs T, Barbosa-cánovas GV. Ultrasound Technologies for Food and Bioprocessing. Springer. 2011. [Epub ahead of print]. DOI: 10.1007/978-1-4419-7472-3

[20] Chemat F, Zill-E-Huma R, Khan MK. Applications of ultrasound in food technology: Processing, preservation and extraction. Ultrasonics Sonochemistry. 2011;18:813-835

[21] Çavdar HK, Yanik DK, Gök U, et al. Optimisation of microwave-assisted extraction of pomegranate (Punica granatum L.) seed oil and evaluation of its physicochemical and bioactive properties. Food Technology and Biotechnology. 2017;55:86-94

[22] Taticchi A, Esposto S, Veneziani G, et al. The influence of the malaxation temperature on the activity of polyphenoloxidase and peroxidase and on the phenolic composition of virgin olive oil. Food Chemistry. 2013;136:975-983

[23] Bejaoui MA, Beltrán G, Sánchez-Ortiz A, et al. Continuous high power ultrasound treatment before malaxation, a laboratory scale approach: Effect on virgin olive oil quality criteria and yield. European Journal of Lipid Science and Technology. 2016;118:332-336. [Epub ahead of print]. DOI: 10.1002/ejlt.201500020

[24] Aydar AY. Physicochemical characteristics of extra virgin olive oils obtained by ultrasound assisted extraction from different olive cultivars. International Journal of Scientific and Technology Research. 2018;4:1-10

[25] Bejaoui MA, Beltran G, Aguilera MP, et al. Continuous conditioning of olive paste by high power ultrasounds: Response surface methodology to predict temperature and its effect on oil yield and virgin olive oil characteristics. LWT - Food Science and Technology. 2016;69:175-184

[26] Yanik DK. Alternative to traditional olive pomace oil extraction systems: Microwave-assisted solvent extraction of oil from wet olive pomace. LWT - Food Science and Technology. 2017;77:45-51

[27] Kadi H, Moussaoui R, Djadoun S, et al. Microwave assisted extraction of olive oil pomace by acidic hexane. Iranian journal of chemistry and chemical engineering. 2016;35:73-79

[28] Malheiro R, Oliveira I, Vilas-Boas M, et al. Effect of microwave heating with different exposure times on physical and chemical parameters of olive oil. Food and Chemical Toxicology. 2009;47:92-97

[29] Leone A, Romaniello R, Tamborrino A, et al. Microwave and megasonics combined technology for a continuous olive oil process with enhanced extractability. Innovative Food Science and Emerging Technologies. 2017;42:56-63

[30] Leone A, Tamborrino A, Zagaria R, et al. Plant innovation in the olive
oil extraction process: A comparison of efficiency and energy consumption between microwave treatment and traditional malaxation of olive pastes. Journal of Food Engineering. 2015;146:44-52

[31] Clodoveo ML, Paduano A, Di Palmo T, et al. Engineering design and prototype development of a full scale ultrasound system for virgin olive oil by means of numerical and experimental analysis. Ultrasonics Sonochemistry. 2017;37:169-181

[32] Amirante R, Paduano A. Ultrasound in Olive Oil Extraction. United Kingdom: Intech Open; 2018. pp. 43-53

[33] Amirante R, Clodoveo ML. Developments in the design and construction of continuous full-scale ultrasonic devices for the EVOO industry. European Journal of Lipid Science and Technology. 2017;119:1-5

[34] Achat S, Tomao V, Madani K, et al. Direct enrichment of olive oil in oleuropein by ultrasound-assisted maceration at laboratory and pilot plant scale. Ultrasonics Sonochemistry. 2012;19:777-786

[35] Japón-Luján R, Janeiro P, De Castro MDL. Solid-liquid transfer of biophenols from olive leaves for the enrichment of edible oils by a dynamic ultrasound-assisted approach. Journal of Agricultural and Food Chemistry. 2008;56:7231-7235

[36] European Union Commission Regulation. (EEC) No 2568/91. Brussels: Official European Commission Journal; 1991

[37] Beltrán Ortega J, Martínez Gila DM, Aguilera Puerto D, et al. Novel technologies for monitoring the in-line quality of virgin olive oil during manufacturing and storage. Journal of the Science of Food and Agriculture. 2016;96:4644-4662