Chapter

Emerging Extraction Technologies in Olive Oil Production

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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

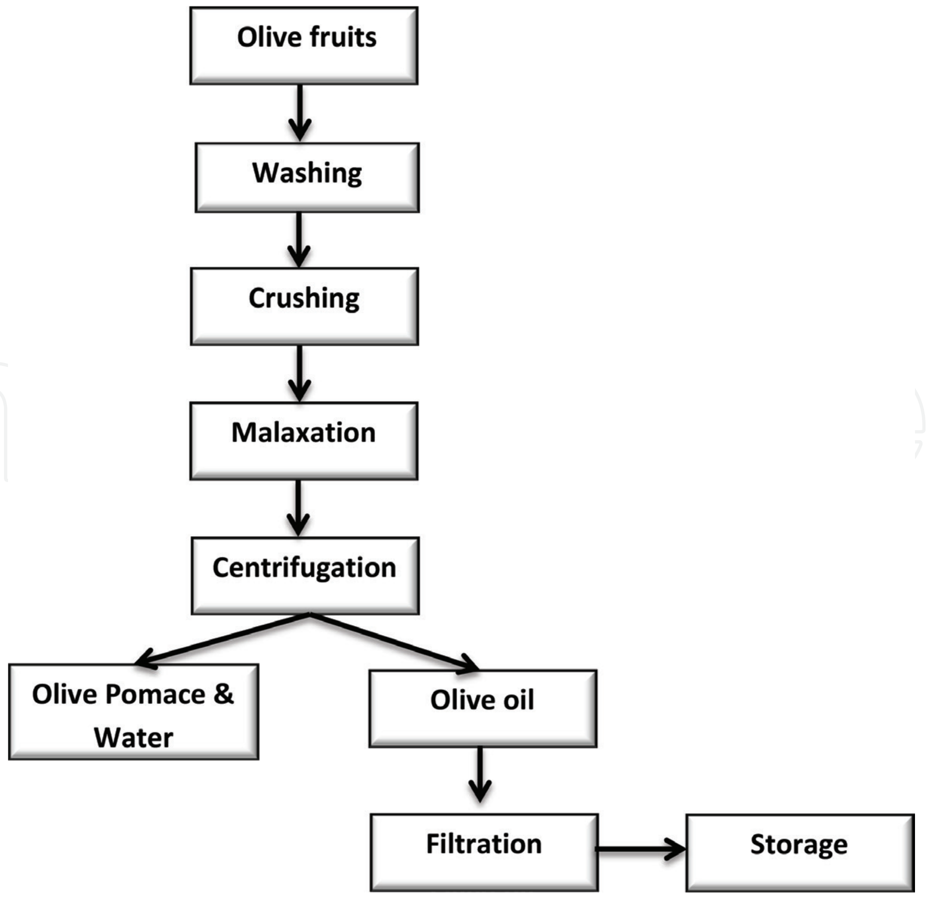

Figure 1.
Flow chart of olive oil extraction.

period of time. [7]. 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]
Ogliarola 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]

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.

2. Ultrasound applications in olive oil extraction

In the olive oil industry, ultrasound is the 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/cm^2) 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 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 malaxated 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 malaxated 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

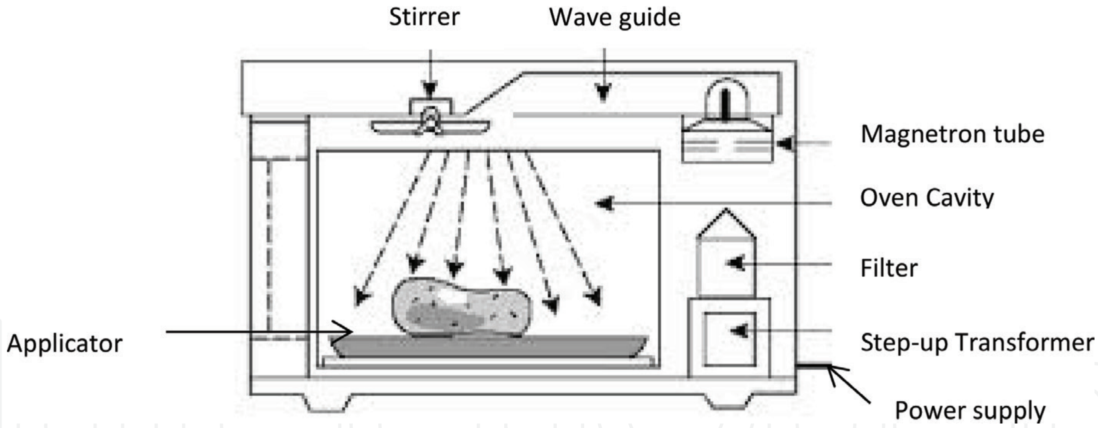

Figure 2.
Microwave oven parts.

ultrasound and microwave treatments compared with the oils that were extracted from the olive paste without malaxation. [14].

Yanık 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 (17.8 meq O_2/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."

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