

Green Extraction in Olive Mill Waste: A Sustainable Approach to Valorisation

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Introduction

The olive industry, a cornerstone of Mediterranean agriculture, produces vast amounts of waste each year. Olive mill waste (OMW) is primarily composed of pomace, leaves, and wastewater resulting from olive oil extraction (Mateo & Maicas, 2015). Traditionally viewed as a byproduct with limited value, OMW poses environmental challenges due to its high organic load and potential pollution (Alonso-Fariñas *et al.*, 2020). However, with the growing emphasis on sustainability and circular economies, innovative techniques known as green extraction are emerging, transforming OMW into valuable resources while minimizing environmental impacts (Gullón *et al.*, 2020). This article explores the green extraction methods employed in the valorisation of olive mill waste, highlighting their benefits and potential applications.

Understanding Olive Mill Waste

Olive mill waste (OMW) is a significant environmental concern, containing 98% of the olive fruit's total phenols (Obied *et al.*, 2005). It is generated during the oil extraction process, where olives are crushed, mixed, and separated to yield oil (Leite *et al.*, 2022). This waste consists of pomace and olive mill wastewater (OMWW), both rich in valuable compounds (Khdair & Abu-Rumman, 2020). During traditional olive oil production, the crushing stage results in the greatest loss of phenolic compounds (60%) and oleuropein (70%), while pomace retains 26% of phenolics and 33% of antioxidant activity (Goldsmith *et al.*, 2014). OMWW, when dried, exhibits a 3.5-fold concentration of phenolic compounds and a 2.7-fold increase in antioxidant activity compared to whole olives (Goldsmith *et al.*, 2014). To address environmental concerns and recover valuable compounds, a pilot-scale treatment system has been developed, involving filtration, adsorption, and chromatography. This process results in reduced

wastewater pollution and the recovery of polyphenols and lactones with high antioxidant activity (Agalias *et al.*, 2007).

The Green Extraction Concept

Green extraction refers to sustainable methods that maximize the recovery of valuable bioactive compounds from agricultural waste while minimizing energy consumption and the use of harmful solvents. In the context of OMW, various green extraction techniques can be employed, including:



Figure 1: Green extraction and valorisation of olive mill waste

Solvent Extraction with Natural Solvents:

Supercritical fluid extraction (SCFE), particularly with supercritical CO₂, has emerged as a highly efficient and environmentally friendly technique for the recovery of phenolic compounds and antioxidants from natural sources (Díaz-Reinoso *et al.*, 2006; Júnior *et al.*, 2010). This method offers significant advantages over conventional solvent-based extraction, including minimal degradation of thermolabile phenolics and preservation of their bioactive properties, such as antioxidant, anti-inflammatory,

antidiabetic, and anticancer effects (Júnior *et al.*, 2014). The efficacy of SCFE is influenced by parameters such as temperature, pressure, co-solvent use, and extraction time, allowing for fine-tuning of conditions to maximize yield and purity. In parallel, the use of natural solvents like ethanol and water further enhances the sustainability of phenolic extraction, reducing toxicological risks and environmental impact. Recently, green deep eutectic solvents (NaDES) have also gained attention as non-toxic, biodegradable alternatives to conventional solvents. These solvents can enhance extraction efficiency and selectivity, with performance dependent on factors such as solvent composition, molar ratio, water content, and solid-to-solvent ratio (Ali Redha, 2021). Collectively, these green extraction strategies align with sustainable development goals and are increasingly being adopted in food, pharmaceutical, and cosmetic applications.

Microwave-Assisted Extraction (MAE):

MAE is an innovative technique that uses microwave energy to extract valuable compounds from plant materials (Delazar *et al.*, 2012). MAE offers several advantages over traditional extraction methods, including shorter processing times, reduced solvent usage, higher extraction rates, and lower costs (Delazar *et al.*, 2012; Veggi *et al.*, 2012). The process involves complex phenomena such as electromagnetic, heat, and mass transfer, which can be optimized to target specific compounds of interest (Veggi *et al.*, 2012). Key parameters affecting MAE efficiency include solvent characteristics, volume, exposure time, temperature, plant material properties, and microwave power (López-Salazar *et al.*, 2023). MAE is considered environmentally friendly due to its use of non-toxic solvents and lower energy consumption (López-Salazar *et al.*, 2023). This technique has shown promise in extracting bioactive compounds from various plant sources for applications in nutraceuticals and functional foods (Sadeghi *et al.*, 2017).

Ultrasound-Assisted Extraction (UAE):

UAE is an efficient method for extracting bioactive compounds from fruit and vegetable processing by-products, including olive pomace (Kumar *et al.*, 2020). UAE offers

advantages over conventional extraction techniques, such as reduced extraction time, lower temperature requirements, and decreased energy and solvent consumption (Xie *et al.*, 2019; Madureira *et al.*, 2023). The process can be optimized by adjusting parameters like ethanol concentration, temperature, time, and ultrasound intensity (Xie *et al.*, 2019). UAE has been shown to yield higher extraction efficiencies for compounds like hydroxytyrosol and tyrosol compared to heat-assisted extraction (HAE), with extraction yields of up to 30% (Madureira *et al.*, 2023). However, HAE extracts may exhibit superior bioactive properties, including antioxidant, antidiabetic, anti-inflammatory, and antibacterial activities (Madureira *et al.*, 2023). Overall, UAE presents a promising, environmentally friendly approach for recovering valuable compounds from agricultural waste products (Xie *et al.*, 2019; Kumar *et al.*, 2020).

Enzymatic Extraction:

Enzymatic extraction is an eco-friendly and effective method for obtaining bioactive compounds from natural sources, particularly plants and algae (Alam *et al.*, 2017; Wijesinghe & Jeon, 2013). This technique employs hydrolytic enzymes to break down cell walls and membranes, enhancing the release of secondary metabolites and improving mass transfer during extraction (Alam *et al.*, 2017; Łubek-Nguyen *et al.*, 2022). Enzyme-assisted extraction has been successfully used to obtain various bioactive compounds, including phenolics, polysaccharides, peptides, pigments, and terpenes (Wijesinghe & Jeon, 2013; Łubek-Nguyen *et al.*, 2022). The method offers advantages over conventional extraction techniques, such as increased yield, selectivity, and preservation of heat-sensitive compounds (Puri *et al.*, 2012). Furthermore, enzymatic extraction has potential applications in the food, nutraceutical, and pharmaceutical industries, as demonstrated by the extraction of stevioside from *Stevia rebaudiana* (Puri *et al.*, 2012; Łubek-Nguyen *et al.*, 2022).

Fermentation:

Recent research highlights the potential of fermentation processes to enhance the extraction and utilization of bioactive compounds from OMW. Microbial fermentation can increase hydroxytyrosol levels in OMW extracts, with *Wickerhamomyces*

anomalus and *Lactiplantibacillus plantarum* showing promising results (Romeo *et al.*, 2021). Various fungi have been employed to produce valuable enzymes and exopolysaccharides from OMW, as well as to improve its agronomic use (Crognale *et al.*, 2006). Fermentation is recognized as an effective approach for transforming food industry wastes into value-added products, including bioactive compounds like polyphenols and polysaccharides (Sadh *et al.*, 2018). OMW-derived bioactive molecules have potential applications in agriculture as fertilizers, biostimulants, and biopesticides, offering sustainable alternatives to synthetic substances (Sciubba *et al.*, 2020). These studies demonstrate the potential of fermentation processes to valorise OMW, improving extraction efficiency and converting waste into useful products.

Each of these green extraction methods holds promise for improving the economic value of olive mill waste while adhering to sustainable practices. These techniques not only enhance the recovery of antioxidants and phenolic compounds but also contribute to the development of value-added products, such as natural preservatives, functional foods, and cosmetics.

Environmental and Economic Benefits

Green extraction techniques have emerged as sustainable alternatives to traditional methods for extracting natural products, offering environmental and economic benefits. These eco-friendly approaches aim to reduce energy consumption, minimize solvent use, and improve extraction efficiency (Chemat & Strube, 2015; Câmara *et al.*, 2022). Supercritical CO₂ and enzyme-assisted extractions are recognized as green alternatives to conventional methods like expeller pressing and organic solvent extractions, though their economic feasibility is still debated (Lavenburg *et al.*, 2021). Various innovative techniques, including ultrasound-assisted extraction, microwave-assisted extraction, and pressurized liquid extraction, have been developed to enhance selectivity and sensitivity while reducing harmful effects on operators and the environment (Câmara *et al.*, 2022; Shrivastav *et al.*, 2024). These methods align with green chemistry principles and offer potential applications in biological, food, and environmental matrices. The adoption of green extraction techniques can lead to more

efficient use of resources and promote sustainability in various industries (Chemat & Strube, 2015; Shrivastav *et al.*, 2024).

Conclusion

As the olive oil industry seeks sustainable practices, green extraction presents a promising avenue for the valorisation of olive mill waste. By employing eco-friendly techniques to recover valuable bioactive compounds, the industry can mitigate environmental risks while enhancing economic opportunities. The transition from waste management to resource recovery not only benefits olive oil producers but also contributes to broader sustainability goals. With continued research and innovation in green extraction methods, the future of olive mill waste looks bright, paving the way for a more sustainable and circular approach in the agricultural sector.

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