# Sustainable Management of Waste in the Olive Oil Sector

Guillermo Garcia-Garcia(✉), Antonio Pérez, and Mónica Calero

Department of Chemical Engineering, Faculty of Sciences, Avda. Fuentenueva, s/n 18071 Granada, Spain
guillermo.garcia@ugr.es

**Abstract.** One of the challenges of olive oil production is the management of the large amounts of waste generated by the sector. Only 20% of the mass of the olive fruit ends up as olive oil. Most of the remaining biomass consists of the pulp and skin of the fruit, known as olive pomace. This olive pomace still contains oil, which is usually extracted with hexane and sold as lower-quality olive pomace oil. The biomass left over after extraction is called olive cake and is usually combusted to produce electricity or heat. Current waste management practices in the olive sector have a significant environmental impact and provide little economic benefit to olive oil producers. This work proposes a sustainable alternative to valorize olive cake, the main waste from the olive oil sector. The overall objective is to sustainably produce chemical compounds with market value, such as polyphenols, inositol, carbohydrates, bioethanol, tar and ash. The processes proposed also generate heat, that can be reused in the waste management alternative proposed. These processes can be integrated in a biorefinery that would be able to produce olive oil as the primary product, along with a wide range of other products with high market potential.

**Keywords:** Waste valorization · olive pomace · olive cake · hydrolysis

## 1 Introduction

Olive oil is valued by consumers for its unique health benefits and organoleptic properties. The Mediterranean region, particularly Spain, Italy, Greece, Turkey and Tunisia, is the world's largest producer of olive oil [1, 2]. Global production is largely dominated by Spain, which produces more than 40% of the world production and is the world's leading exporter of olive oil [3, 4]. In Spain, and to a lesser extent in the aforementioned Mediterranean countries, olive oil is an important product for the food sector and for the overall national economy. In fact, the price of olive oil has risen sharply in recent years, with prices in 2024 doubling those from the average of the previous 5 years, and currently reaching 7.94, 7.73 and 9.45 € per kg in Spain, Greece and Italy, respectively [5]. This is caused by the high consumer demand and recent poor harvests due to intense droughts.

It is therefore clear that the olive oil sector needs to improve its efficiency to remain competitive in the market. Inputs to the production process, particularly water, should be


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minimized as much as possible. Similarly, outputs that currently provide no value to olive oil businesses should be processed in order to enable these businesses to add value to their operations and generate additional income, which would then allow product prices to be reduced. Indeed, the olive oil sector currently generates large amounts of waste materials that not only provide no economic benefits, but also generates environmental impacts as well as economic costs. This is slowly changing with recent efforts to modernize the olive oil production processes and the entire olive oil supply chain. As a result, this industrial sector is currently demanding further advances to optimize its operations.

Research and development to propose more sustainable waste management treatments has been developing for years in the food sector [6, 7]. Several options have been proposed, such as anaerobic digestion to obtain bioenergy [8, 9], composting to fertilize soils [10, 11] and thermal treatments to obtain heat [12, 13]. However, a promising alternative is to use such food waste as a feedstock to obtain valuable compounds. Current research is investigating various techniques to recover useful materials and thus valorize food waste [14, 15]. Some researchers are investigating this approach in the olive oil sector (e.g. [16–18]), however this option is not yet implemented at industrial level.

The aim of this work is to find an alternative waste management solution to help the olive oil sector become more economically and environmentally sustainable. This paper reviews the most common way of managing waste in the olive oil sector and then proposes an alternative waste management solution that allows the recovery of several valuable compounds.

## 2 Current Waste Management Practice

One of the challenges of olive oil production is the management of the large amounts of biomass waste generated by the sector. Only 20% of the mass of the olive fruit ends up as olive oil. Most of the remaining biomass consists of the pulp and skin of the fruit, known as olive pomace (Fig. 1, left). This olive pomace still contains oil, so olive pomace is usually dried and the remaining oil is extracted with hexane. The resulting olive pomace oil is sold as lower-quality olive pomace oil. The biomass left over after extraction is called olive cake (Fig. 1, right). Olive cake is usually combusted to produce electricity or heat. Another residue from olive oil production is the olive stone, which is also combusted to produce energy. The heat generated in the combustion process is sometimes used in the drying process. The block flow diagram of the waste management practice described in this section is shown in Fig. 2.

The main advantage of the current waste management practice is the production of olive pomace oil, which has a good market position. However, the drying process requires a high energy input, which is not always available from the combustion process. In addition, both drying and combustion emit particles into the atmosphere, which generate an environmental impact. In addition to improving these two processes, there are opportunities to recover valuable compounds from the olive cake. This would also reduce the number of volatile solids emitted during combustion. Based on the authors' knowledge and discussions with waste managers from the olive oil sector, an alternative waste management solution is proposed in the next section Sect. 3.

**Fig. 1.** Left: olive pomace, right: olive cake.

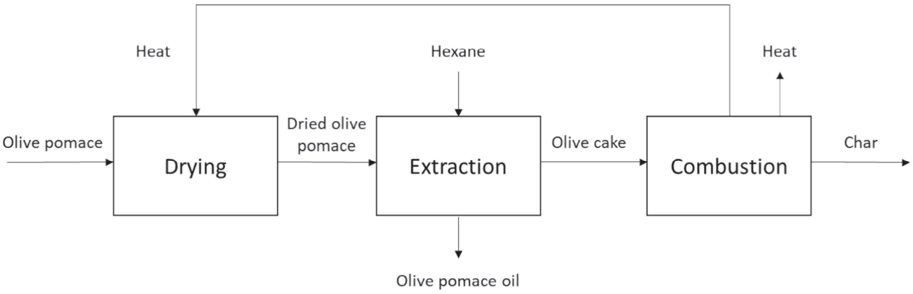


**Fig. 2.** Conventional waste treatment process for olive pomace.

## 3 Proposed Waste Management Alternative

This work proposes a waste management alternative to valorise olive cake, the main waste from the olive oil sector. The overall objective is to produce chemical compounds with market value, as well as heat that can be used in the treatment processes themselves. In addition, the processes proposed operate at low temperatures to save energy and use water as the only reagent. Therefore, the proposed waste management alternative is a sustainable solution that allows the recovery of valuable compounds, which saves the conventional production of such compounds, as well as uses minimal material and energy inputs.

The proposed waste management alternative is shown in Fig. 3. It starts with the drying of olive pomace and the extraction of olive pomace oil with hexane, as is currently done. This is unchanged due to the large share that olive pomace oil already has on the market. The resulting olive cake is then subjected to a hydrothermal treatment at 30ºC, which produces a liquid phase that is filtered to extract polyphenols and inositol. Both compounds have been shown to be beneficial to human health and therefore have important applications in the food and pharmaceutical industries. Other carbohydrates, for instance sugars, can also be extracted and subsequently fermented to produce bioethanol.

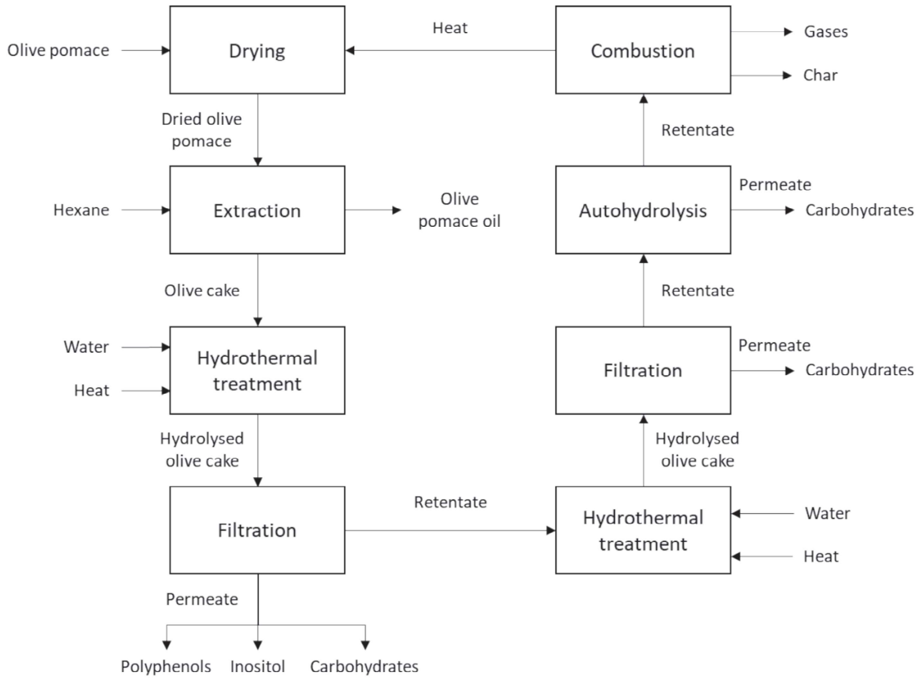


**Fig. 3.** Proposed waste treatment processes for olive pomace.

The solid phase remaining after the first hydrothermal treatment is then subjected to a further hydrothermal treatment at 70ºC. The liquid phase obtained, as well as the previous permeate, is a good source of carbohydrates. The solid remaining after the second hydrothermal treatment is then subjected to autohydrolysis, which produces a sugar-rich solution and a solid that can be thermally treated for energy recovery. This solid is combusted and the heat generated is used in the drying process at the beginning of the process chain. Alternatively, future work will explore the gasification of the solid, with the objective of producing a gas that is combusted to recover the heat, and tar and ash as remaining liquid and solid phases, respectively. Tar has a wide range of applications, including in the production of varnishes, adhesives and preservatives. Ash can be employed as an adsorbent to replace activated carbon.

Preliminary tests have demonstrated the feasibility of the block flow diagram depicted in Fig. 3. A mass concentration of 25% w/w for the olive cake in water has been proven to be adequate for the hydrothermal treatment. Vacuum filtration was used for the separation of the permeate and retentate. Nine repetitions of the hydrothermal treatment at 30ºC were conducted with samples of 500 g of dried olive cake, obtaining a homogeneous amount of permeate (mean: 1128.06 g, standard deviation: 79.54 g) and retentate (mean: 807.63 g, standard deviation: 71.41 g). Seven tests were carried out for the hydrothermal treatment at 70ºC, also with 500 g of starting feedstock. The results obtained were also homogeneous for both the permeate (mean: 927.71 g, standard deviation: 93.52 g) and retentate (mean: 903.98 g, standard deviation: 61.17). Following the completion of both hydrothermal treatments, the solid retentates had a moisture content of 50–60%. The solid retentates were fully dried in an oven at 105ºC prior to undergoing the subsequent process indicated in the block flow diagram shown in Fig. 3.

Autohydrolysis must be conducted at a considerably higher temperature. Several combinations of temperature, reaction time and concentrations are possible and are currently being tested. It is imperative to identify a compromise solution that strikes a balance between the maximum carbohydrates obtained in the permeate phase and the minimum temperatures and reaction times necessary to save energy. Ultimately, the retentate was subjected to drying and combustion. This process results in the emission of gases into the atmosphere; however, it does yield a solid char that can be activated and employed as an activated carbon substitute.

The proposed waste treatment processes described above allow the production of a comprehensive range of valuable chemicals that include polyphenols, inositol, carbohydrates, bioethanol, tar and ash. This contrasts with the current predominant approach in the sector, whereby the majority of outputs are released into the atmosphere or deposited in nearby soil. Moreover, we propose an innovative approach to optimizing the value of biomass management through the utilization of the biorefinery concept. A biorefinery is an industrial plant that utilizes biomass as a feedstock to produce a diverse range of valuable products, including chemicals, foodstuffs and animal feed, as well as energy in the form of electricity, heat or biofuels. While previous work has been conducted on the potential implementation of biorefineries in the olive oil sector, there is a lack of studies exploring the valorization of olive cake, particularly under mild conditions. Our proposed waste management alternative to valorize olive cake could be integrated into such a biorefinery, thereby enabling the production of olive oil as the main product, along with a diverse array of other valuable products that could also be commercialized.

## 4 Conclusions

The production of olive oil represents a significant industrial sector in numerous countries situated in the Mediterranean region. One of the most significant challenges currently facing this sector is the management of the waste generated throughout the production process, in particular the olive cake obtained from the processing of olive pomace. Presently, the majority of the olive cake is combusted. This work proposes a waste management alternative for olive cake to obtain polyphenols, inositol, carbohydrates, bioethanol, tar and ash. The heat released in the processes can be recovered and used in the treatment processes themselves. Further work could extend this approach to treat other materials generated in the sector, such as olive stones, leaves and branches, with a view to integrating them into a biorefinery. Consequently, a full-scale biorefinery would be capable of producing olive oil as its primary product, in addition to a multitude of other products that have a considerable market potential. Such an approach would have the dual benefit of increasing revenues for olive oil businesses and reducing the environmental impact of current waste management practices.

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