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Review

Olive pomace bioactives for functional foods and cosmetics

Alexandros Tsoupras[1,*], Eirini Panagopoulou[2] and George Z. Kyzas[1]

[1] Hephaestus Laboratory, School of Chemistry, Faculty of Science, Democritus University of Thrace, Kavala University Campus, St Lukas, 65404, Kavala, Greece
[2] Department of Dietetics and Nutrition, Harokopio University, 70, El. Venizelou Ave., Kallithea 17676, Greece

* **Correspondence:** Email: atsoupras@gmail.com; atsoupras@chem.duth.gr; Tel: +302510462228.

Abstract: The reuse and valorization of olive mill by-products, among others, is getting attention in the food and drugs-cosmetics sectors, due the recovery of their essential bioactive compounds in order to incorporate them as ingredients in functional foods, cosmetics, and pharmaceuticals. Olive pomace represents olive mill's main residue (by-product), and it is a sustainable and of low-cost renewable source of several bioactive compounds, while its valorization can reduce its environmental impact and make it an additional economic resource for food industries in a circular economy design. In this article, the natural bio-functional compounds of olive pomace with antioxidant and anti-inflammatory bioactivities are thoroughly reviewed. The incorporation of such bioactives as ingredients in functional foods and cosmetics is also discussed in detail. The limitations of such applications are also presented. Thus, promising techniques, such as encapsulation, and their applications for stabilizing and masking undesirable characteristics of such compounds, are also exhibited. The so far promising in vitro outcomes seem to support further in vivo assessment in trials-based setting.

Keywords: by-products; olive mill; olive pomace; bioactives; anti-inflammatory; antioxidant; functional foods; cosmetics; encapsulation

1. Introduction

The by-products of food industry constitute a huge problem both for environmental and economic impacts [1–3]. For this purpose, there is an increasing interest in reusing food industry by-products, as they may represent potential energy and/or bioactives' sources. Food by-products bioactive compounds may be used for the fortification of several foods, pharmaceuticals, and cosmetics [4,5]. In the Mediterranean region, olive oil is the main plant-based edible oil, consumed lavishly, as a source of several bioactives with health effects worth mentioning [6]. Nowadays, the production of olive oil represents a main income for the Mediterranean countries, as only 2% of the world's production is located away from this area. The production of virgin olive oil is a chain that leads to huge amounts of wastes, namely olive leaves and wooden parts and by-products, namely olive pomace and wastewater; they represent a crucial issue for the Mediterranean countries, since the increasing of olive oil production leads to the simultaneous increase of such wastes and by-products quantities in very short periods of time [7,8].

For several years, these olive mill "wastes" were treated according to waste management rules, and, as a result, countless environmental issues among with a huge economic loss and a consequential loss of significant amounts of bioactives were unavoidable. Recently, a novel economic concept, namely the circular economy, has the ambitious purpose of expanding product lifespan, promoting recycling and re-using, and closing the product lifecycle [9]. It focuses on economic and environmental sustainability, arguing that agri-food by-products are not waste, but resources to be valorized [9]. Thus, researchers are paying more attention to the reuse of olive mill by-products, among others, via the recovery of their essential bioactive compounds in order to incorporate them in functional foods, cosmetics, and pharmaceuticals [10,11], aiming in the production of final products with health promoting properties.

According to the literature, the Mediterranean diet, an integral part of which is virgin olive oil, is a diet pattern with several beneficial effects on the prevention of chronic non-communicable diseases, namely cancer, diabetes, hypertension, and neurodegenerative diseases, while the risk factors of the cardiovascular diseases were positively affected by olive oil consumption. Such findings demonstrate that the bioactive compounds, namely lipids, including tocopherols (lipid vitamin E) and phenolic microconstituents, presented in virgin olive oil and thus in olive oil by-products, are responsible for several health promoting and well-being properties. Interestingly, according to the literature, olive pomace is a significant source of bioactive compounds, since, for example, it retains most of the phenolic content of the olive fruit (only 1–2% of the phenolic content is found in olive oil) [11,12]. On the other hand, the amounts of bioactives, organic load along with low pH, make olive pomace phytotoxic and non-biodegradable [13,14]. Thus, since olive pomace represents a matrix rich in bioactives, is a potential raw ingredient for the production of sustainable functional products in the food, pharmaceutical, and cosmetics sectors [14].

The present study intends to examine the utilization of olive oil pomace in food, pharmaceutical, and cosmetic products, as well as provide evidence of the potential in the prevention of several diseases, health promotion, and thus, well-being.

2. Materials and methods

During the process of selecting the digital libraries for the automated search strategy, we chose to utilize the widely recognized Scopus database for the following reasons: (i) its extensive coverage of research across various scientific fields, and (ii) the availability of robust tools for systematic searches [15,16]. The final search query comprised the following terms: "olive", "by-products", "olive pomace" AND "food" AND "cosmetic" AND "applications", as well as "tocopherols" or "hydroxytyrosol" AND "effects, "antioxidant", "antiaging", "sunscreen", "antimicrobial", "anti-inflammatory", "cardiovascular diseases", "diabetes", "cancer" "hypertension" or "neurodegenerative diseases". "Sustainability" AND "food" or "cosmetic" AND "by-products" were also searched as well as "extraction" AND "olive oil by-products". Articles on "nanoformulations" or "encapsulation" AND "olive pomace" were part of this research, too. This query was applied to the titles, abstracts, and keywords of articles, and the search process was concluded in January 2024.

2.1. Inclusion Criteria

The selection criteria were determined by considering the metadata available from Scopus, with the eligible studies meeting the following criteria: (i) be exclusively research articles; (ii) be written in English; and (iii) be published between 2014 and 2024. A limited number of important articles prior to 2014 were also included since they were not previously reviewed thoroughly.

2.2. Exclusion Criteria

Conference papers, books, and short surveys, as well as publications written in languages other than English, were excluded.

2.3. Quality Assessment

To evaluate the articles' quality and relevance, we first reviewed their titles and abstracts, excluding those unrelated to the topic. Subsequently, the remaining articles were thoroughly read to determine whether they met the predefined inclusion criteria and provided pertinent information for this review.

2.4. Intended Audience

The findings of this study are targeted towards academic and industrial scientists in the general fields of functional foods, cosmetics, chemistry, drugs, pharmaceutics, medicine and pharmaceutical chemistry, biochemistry, environmental chemistry, waste management, biology, or even molecular biology, as well as towards healthcare professionals and policymakers. The research offers insights into the potential multifaceted use(s) of olive mill by-products, such as olive pomace, as functional ingredients of novel foods and cosmetics, with health promoting properties, and their role(s) against inflammation since they exhibit significant anti-inflammatory, antithrombotic, and antioxidant activities.

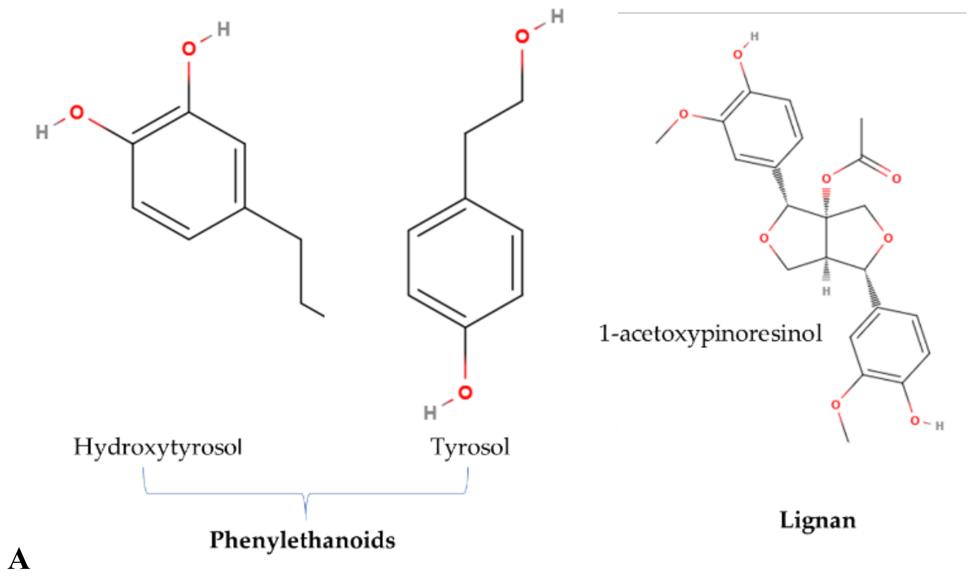
3. Olive mill wastes and by-products

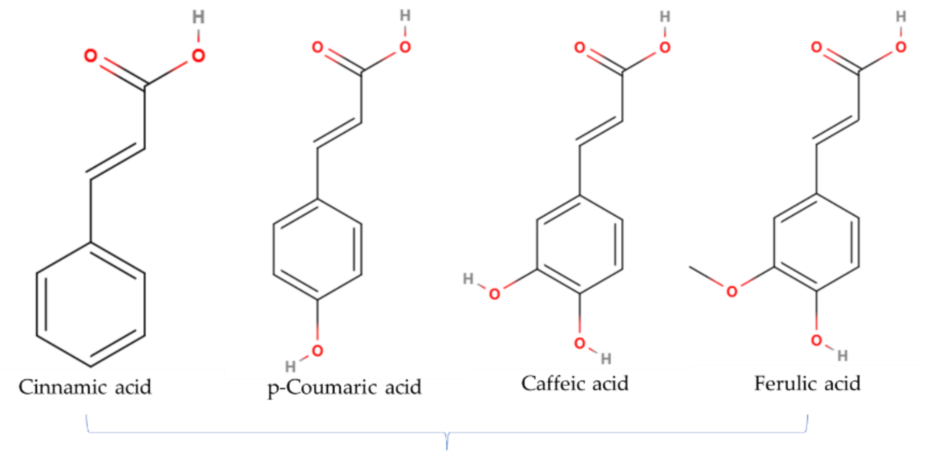
Olive oil is the main product of olive mills along, with a huge amount of waste and by-products. The production of virgin olive oil can be done when mechanical processes are applied, while the next phase may be different and it depends on the olive mill type; there are olive mills that apply two-phase or three-phase centrifugal extraction, or discontinuous extraction with extra pressure [17]. These different applications are followed by differences in the quality and quantity of olive oil, while the amounts of the by-products are also affected. Specifically, when the three-phase procedure is applied, a quantity of water is added to the olive paste, which in the final step are separated into the oily phase, the water phase, and the olive pomace, while in the two-phase olive mills, no water addition is applied in the first olive paste [18]. It is well known that the three-phase procedure produces a higher amount of wastewater due to the extra water addition as compared to the two-phase method, where the wastewater is minimized along with the pomace, which has a higher moisture content [7,19].

Up to 10% of olive mill waste is of olive leaves contained in the raw material that comes to the mills [4,20–22]. It has been demonstrated that olive leaves are sources of bioactive microconstituents, namely phenolics, which play a pivotal role either as food ingredients for the increasing of the shelf-life and the antioxidant capacity of the food products [23–28], or as anti-carcinogenic, anti-inflammatory, and health beneficial agents [29]. Wastewater represents the liquid by-product of the olive mill, and its disposal management is of significance due to its phytotoxic environmental effects [7,30,31]; however, it has been demonstrated that wastewater may improve the properties of soil, since it is a source of potassium, lipids, and organic acids [32]. Interestingly, the utilization of wastewater for the production of biogas has also been proposed from some authors [31,33,34].

The olive pomace represents the main by-product from both the aforementioned separation procedures, while it consists of shattered olive stones, water, and all the remaining from the olive drupes, except for its oil. It should be mentioned that for each ton of olives processed, 0.62 (three-phase, dry weight) and 0.87 (two-phase, wet weight) tons of olive pomace are produced, with a moisture content of 50–65%, depending on the method applied [35]. Currently, the two-phase procedure is preferred by up to 90% of the olive mills [36], since through this method a vertical decrease in the olive mill wastewater is achieved [2]. According to Moubarik (2015) and El-Sheikh (2004), the crushed olive stones that are included in the olive pomace may be used either as fuel, or for the production of activated carbon [37,38].

Olive pomace content in bioactives, the procedures for the extraction/recovery of such bioactives from the matrix and their incorporation for the production of functional, novel products, are extensively discussed in the following paragraphs, since researchers have aimed to find out alternative and sustainable ways to use olive pomace.





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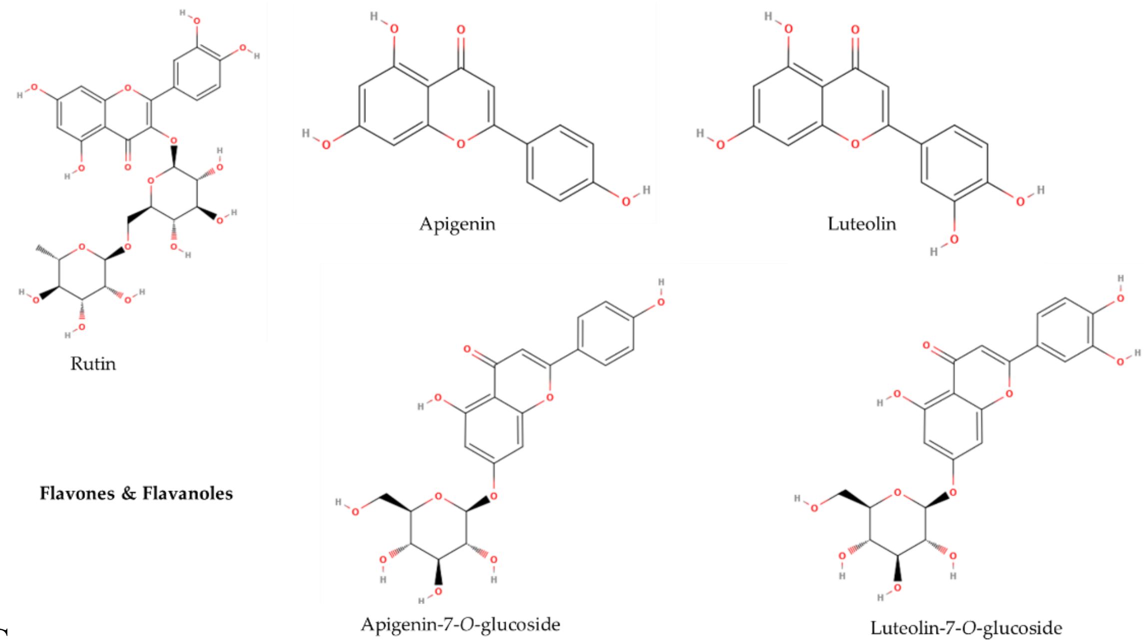

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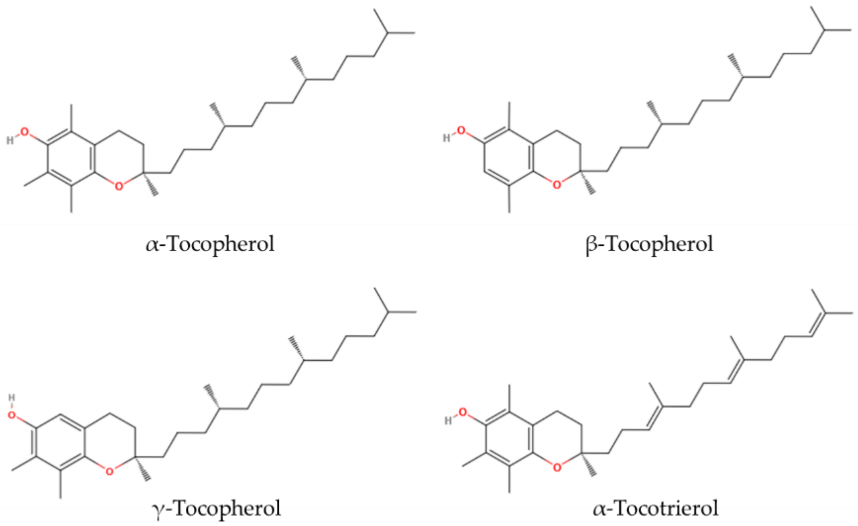

Tocopherols

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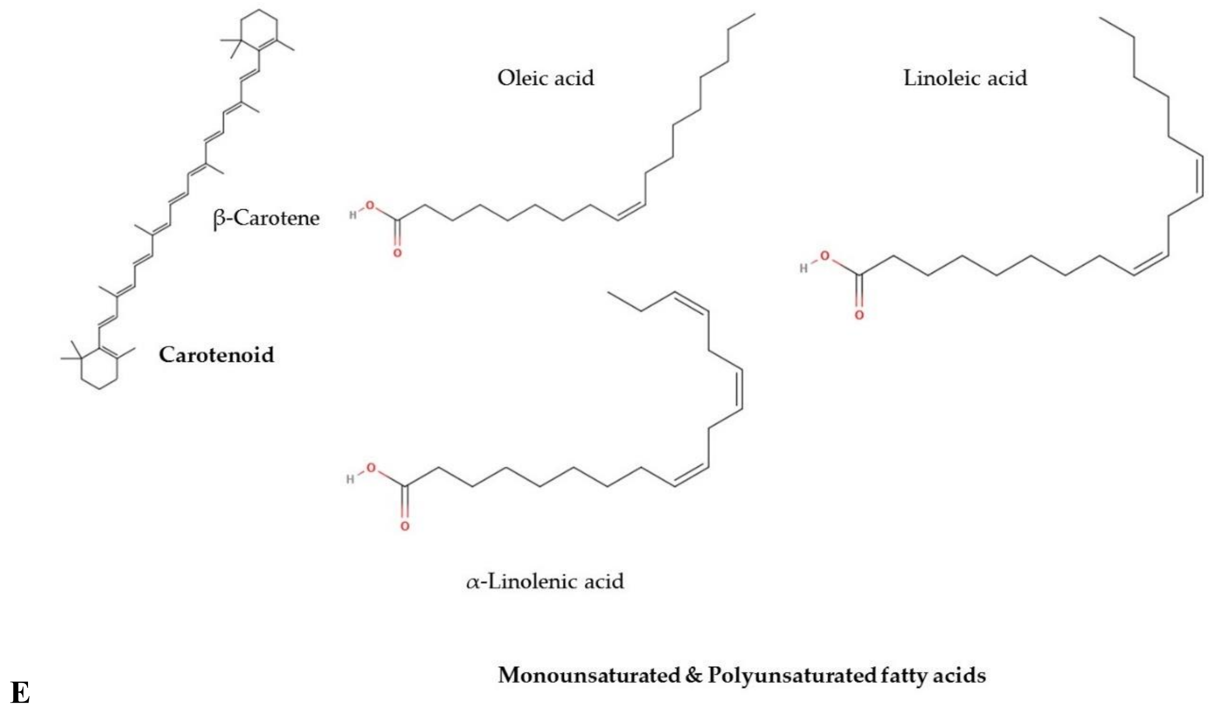

Figure 1. Olive pomace main bioactives. Structures were obtained from https://molview.org/ (assessed on 31st of January 2024). Source: A ([2,39,40]); B ([11,41–43]); C ([44–48]); D ([11,49,50]); E ([11,40,49]).

4. Olive pomace

4.1. Olive and olive pomace constituents

Several parameters affect the olive oil content in bioactives, and therefore the composition of the olive pomace in these microconstituents; irrigation, storage time, and the extraction process are potentially the key factors [18,39–42]. Olive fruit, and thus olive pomace, is a source of several nutrients, namely lipids, dietary fiber, minerals, and oligosaccharides [43], while its content in microconstituents, such as phenolic compounds and lipid soluble vitamins, is remarkable [11,44,45]. Among others, phenolic alcohols of olive fruit, namely tyrosol and hydroxytyrosol [30], numerous flavonoids, namely apigenic, hesperidin, anthocyanins and quercetin [46,47]; phenolic acids, namely chlorogenic, caffeic, sinapic, protocatechuic, cinnamic and ferulic acid [41,48]; secoiridoids, such as comselogoside, hydroxytyrosyl acyclodihydroelenoate, and dialdehyde, and 3,4-dihydroxyphenyl-ethanol-elenolic ether linked to hydroxytyrosol, which is produced during the malaxation of the olive drupes [46,49–52], while other polyphenols, namely oleuropein, verbascoside [11,46,53–55], p-cresol, and dimethyl-oleuropein, have also been identified and quantified in olive fruits [56–60] (Figure 1). Additionally, olives are rich in tocopherols, tocotrienols, carotenoids, and squalene [11,43,61–63].

4.2. Olive pomace bioactives and their general health promoting properties

Significant amounts of these bioactives remain in the olive pomace and thus can be recovered, while their elicitation and recovery from the olive pomace are key factors for their utilization; thus, olive pomace is a by-product that deserves scientists' attention due to its potential health improving properties [64]. Additionally, it is well-known that olive pomace phenolic compounds exhibit significant antioxidant activities, and thus their utilization in functional, novel products has been suggested [65]. Olive-related by-products' phenolics have been reported to be great free radicals' scavengers in both in vitro, and also in cell cultures and in vivo models, in which radical-generator compounds, namely ABTS+ (2,2-azinobis-(3-ethylbenzothiazoline-6-sulfonic acid), DPPH• (1,1-diphenyl-2-picrylhydrazyl), FRAP (ferric anion reducing antioxidant power), TEAC (trolox equivalent antioxidant capacity), and ORAC (oxygen radical absorbance capacity), have been tested for these antioxidant properties [47,66]. Additionally, olive phenolics' antibacterial activities against several bacteria, namely Bacillus cinerea, Bacillus subtilis, Escherichia coli, and Staphylococcus aureus have also been demonstrated [67].

Hydroxytyrosol (HT) is by far the most investigated among olive pomace polyphenols, and it has been demonstrated that it exhibits antiradical activities rather similar to those of vitamins in different sample types, namely plasma and rats' liver [47,68]; HT has been exhibited to have cardioprotective properties on human cells, while it has been demonstrated that HT, along with oleuropein and caffeic acid, exhibit respective protective effects against low-density lipoprotein (LDL) oxidation [69]. In addition, HT appears to be effective even in low amounts in securing human DNA and red blood cells from oxidation damage, while it has also been proven that HT is a crucial hypoglycemic agent since it acts protectively via strengthening enzymatic actions in rats with diabetes [69]. It is worth mentioning that hydroxytyrosol-rich olive oils have been certified for their ability to maintain consistent levels of lipid antioxidants and LDL cholesterol by the European Food Safety Authority (EFSA) [70].

Also, there are studies that have shown that polar lipids retained in the olive pomace possess anti-thrombotic [71–73] and anti-atherosclerotic activities [73–76] by inhibiting platelet aggregation. The cardio-protective health promoting properties of olive pomace polar lipids seems to be related to their capacity to inhibit the activities of the thrombo-inflammatory mediator, platelet activating factor (PAF), as well as on their ability to reduce PAF-synthesis and induce its catabolism toward reduced PAF-levels and the inflammatory status. Interestingly, olive pomace's polar lipids revealed a higher potency than olive oil's polar lipids in inhibiting PAF-induced aggregation of platelets, as well as against specific PAF binding, while they have also shown regression of formed atherosclerotic plaques and thus strong anti-atherosclerotic cardio-protection.

Consequently, the interest of scientists in the recovery of these bioactives from olive-related by-products, such as olive pomace, and the incorporation of these compounds for the production of functional, novel products has increased. Thus, numerous studies have documented the creation of different functional foods that have been produced by the addition of olive pomace or olive pomace bioactives. On the other hand, very recently the interest of the scientific community has turned to the use of olive pomace or olive pomace extracted bioactives in the cosmeceutical and pharmaceutical sectors.

4.3. Applications in the food industry

A plethora of studies have conducted investigations on the application of olive pomace or olive pomace bioactives in the production of functional foods (Table 2). There is a trend to fortify several food matrices with olive pomace or olive pomace bioactives, since antioxidant and anti-inflammatory properties of these bioactive compounds represent key agents against several chronic disorders, namely type II diabetes, cancer, and cardiovascular diseases [77–81], while at the same time, an increase of the nutritional value of the final food products is achieved. Recipes for the production of bread and biscuits fortified with 6%–10% (w/w) olive pomace powder were used, resulting in products richer in dietary fiber and better antioxidant capacity, and thus a higher prevalence of phenols [82–84]. It is worth mentioning that consumption of fortified biscuits led to a significant increase of the amounts of homovanillic acid and 3,4-dihydroxyphenyl acetic acid, as compared to the control samples, which may consequently minimize oxidative LDL cholesterol; additionally, the raising levels of phenolic acids in urine have suggested a boost of these bioactives' modifications in the intestine [83,84]. Other studies aimed to fortify pasta, respectively, with either olive pomace powder or fermented olive pomace [85,86]. 5% and 10% replacement of durum wheat semolina with olive pomace powder led to increase of the total phenolic content and antioxidant activity in vitro of the products [82,87,88]; when olive paste powder (10–15%) was added in pasta, the final products were richer in fiber, phenols, carotenoids, and tocopherols compared to the control samples [89]. Although such products were accepted by the consumers, the overall output from the organoleptic tests was lower than that of the regular ones [82], suggesting that further studies are needed.

Olive pomace is also added in the diet of fisheries [90–93], rabbits [94], ewes [95,96], buffalos [97], lambs [98], chickens [99], broilers [90], and laying hens [100], with remarkable results (Table 1). Olive pomace-enriched fish diets have increased the bioactive lipids, which exhibit antiaggregatory activity and cardioprotective properties [91,92]. Olive pomace-enriched diets enhanced the activity of lysozyme, which is an important enzyme of the fisheries' innate immune system [93]. When rabbits, lambs, chickens, and broilers were fed with olive pomace-enriched feeds, higher oxidative stability of their meat compared to control was observed [90,94,98,99]. A decrease in atherogenic and thrombogenic indexes and milk with higher content of hydroxytyrosol and tocopherols were observed when ewes and buffalos were fed with olive pomace-enriched feeds [95–97]. Additionally, laying hens fed with olive pomace-enriched feed produced eggs with lower cholesterol levels than the control hens. Meanwhile, genes' downregulations and expressions affected by such supplementation may lead to anti-inflammatory results and have a positive impact on cholesterol [100].

Additionally, a functional yogurt fortified with olive pomace lipid bioactives, administered in 92 overweight but otherwise healthy volunteers in a randomized double-blind, three-arm trial, resulted in reduced activities of the main regulatory enzymes of Platelet-Activating-Factor (PAF) -biosynthesis. Thus, consumption of yogurt fortified with olive pomace may optimize PAF-biosynthesis and catabolic routes [101].

Thus, olive pomace is not merely an undesirable by-product, but rather a source of functional bioactives. It can be utilized for fortifying foods and animal feeds, leading not only to eco-friendly functional final products, but also to potential health promotion.

4.4. Applications in cosmeceuticals and pharmaceuticals

Food industry by-products, such as olive pomace, are a means of bioactive compounds, and thus they represent potential fortification agents, not only for the food industry, but also for the pharmaceutical and cosmetics industries, for the creation of high-added value final products with potential health promoting properties [13,102,103]. The application of olive pomace in these sectors has only recently been investigated. Thus, it is necessary to summarize the results of these few studies in this review.

Table 1. Applications of olive pomace or recovered functional compounds as ingredients in foods.

Functional Food	Bio-Functional Ingredients (olive pomace and/or its Bioactives)	Amount	Aims	Results	References
Pasta	Dried olive pomace	7 & 10%	➢ Shelf-life and quality evaluation	• Improvement of oxidative stability and quality parameters	[88,104]
	Olive pomace powder	5–15%	➢ Nutritional evaluation	• Increase of phenolic content and antioxidant activity increased	[86,89]
Bread	Olive pomace	5 & 10%	➢ Nutritional and sensory evaluation	• Increase of antioxidant activity & fiber content Color, smell and taste were affected	[82,88]
	Olive pomace powder	5–20%	➢ Nutritional and quality evaluation	• The metabolic output of the gut microbiota was increased • Increase of polyphenols and dietary fiber and decreasing of glycemic index • Some physicochemical and sensorial characteristics were modified	[83,84,88,105]
Biscuits	Fermented olive pomace	20%	➢ Shelf-life and quality evaluation	• Increase of polyphenols content and shelf-life	[85]
Fisheries	Olive pomace	8%	➢ The effect of olive pomace in fish feed	• Increased the bioactive lipids	[91,92]
Yogurts	Olive pomace polar lipid bioactives	0.23%	➢ Evaluation of the potential impact of the enriched with olive pomace PAF inhibitors functional yogurt against PAF metabolism	• Reduced activities of the main regulatory enzymes of PAF-biosynthesis	[101]

4.4.1. Skin care

Olive pomace bioactive compounds are categorized as hydrophilics and lipophilics since they have different structures and properties. For lipophilic compounds, namely fatty acids, squalene, and lipid-soluble vitamins, the hydrophilic fraction consists mainly of polyphenols. Some of the bioactive compounds obtained from the olive pomace and their uses in the most common cosmetic applications are listed in Table 2. According to the literature, macronutrients found in the olive pomace, namely, pectins and oligosaccharides, have been shown to improve the physical properties and structure of final products. They also contribute to enhanced oxidative stability, viscosity, and sensory characteristics in skincare products [2,13]. Meanwhile, cellulose, mannitol, hemicellulose, and other sugars found in olive pomace increased oil holding capacity of skincare products [2,13,103].

As for the micro-constituents found in olive pomace, namely polyphenols, squalene [13,104–106], maslinic acid [107–109], and minerals such as K, Ca, and Na [2,13], recent studies have been carried out to investigate their contribution to skincare products [13,103,110–113].

Thus, according to the available literature, polar phenolics have demonstrated several activities, namely antioxidant [2,104,105], antiplatelet aggregation, anti-cancer, antimicrobial, cardioprotective activity, free radical scavenging, and fibroblast proliferation [13,109,111,112] activities. Squalene exhibits emollient and moisturizing activities, and it acts as a biological filter of singlet oxygen and as a sink for lipophilic xenobiotics [13,112,113]. Additionally, maslinic acid has acted as antioxidant agent, and exhibited antiproliferative effects of the murine melanoma cells [107–109].

Table 2. Olive pomace bioactive compounds and some of the more common cosmetic uses.

Bioactive Compounds	Activity	References
Polar Lipids	• Wide range of biotechnological applications include the feed, pharmaceutical, nutraceutical, and dermo cosmetic industries	[114,115]
	• Diverse technological uses in the soap, cosmetics and pharmaceutic industries	[114,116]
	• Several biomedical applications relevant to cosmetics and pharmaceuticals, for instance, as emulsifiers in pharmaceuticals and for the preparation of liposomes for cosmetics and drug delivery	[114,117,118]
	• Anti-inflammatory, antiplatelet, anti-cancer, cardio-protective Antiatherogenic, neuroprotective	[71,74,119,120]
A distinctive fatty acid profile	• Anti-ageing and anti-inflammatory	[121]
Phenolics, including oleuropein and hydroxytyrosol	• Protective effects for human dermal fibroblasts and keratocytes, due to skin anti-ageing and anti-inflammatory properties • Anti-aging, antioxidant, anti-inflammatory, antiplatelet, anti-cancer, anti-microbial, cardio-protective, and free radical scavenging activity • Protection and reduction of skin thickening and wrinkles • Fibroblast proliferation	[2,13,102,103,106,109–111,121]
Pectins and oligosaccharides	• Improvement of the physical and structural properties of emulsions • Oxidative stability, viscosity, texture, sensory characteristics, and shelf-life of products	[2,13]
Mannitol, cellulose, hemicellulose	• Physical and structural properties of hydration • Oil holding capacity	[2,13,103]
Squalene	• Oil emollient, moisturizing, biological filter of singlet oxygen • Absorption site for lipophilic xenobiotics	[13,112,113]
Maslinic acid	• Antioxidant, antiproliferative effect of murine melanoma cells • Anti-inflammatory	[107–109]
K, Ca, Na	• Hydration • Stiffness • pH controlling pH	[2,13]

Antioxidant agents, such as polar phenolic compounds found in the olive pomace, are commonly used in dermatological products for anti-aging purposes, too. Aging represents a rather sophisticated process, and involves intrinsic and extrinsic factors. Several extrinsic factors, namely radiation (UV, IR, visible and blue light) [122–125], smoking, and alcohol consumption have synergistic effects on the skin, such as signs of hyperpigmentation and deep wrinkles [126–129]. These parameters are contributors in the generation of reactive oxygen species (ROS) and reactive nitrogen species (RNS), which cause DNA and protein damage, lipid peroxidation, and extracellular matrix degradation [130,131]. Polyphenols are strong antioxidants since they may contribute in the prevention of skin damage caused by ROS and RNS [13,132,133] and improve skin elasticity, thickness, and moisture when used topically [128,131,134,135]. Thus, polyphenols' activity results in satisfactorily antiaging results [77,136–138]. Additionally, olive polar phenolic compounds, also act as lubricants, result in soft, elastic, and lubricated skin, providing a feeling of well-being.

Additionally, a cream for atopic dermatitis, containing chitosan nanoparticles loaded with hydrocortisone and hydroxytyrosol (HC-HT CSNPs) have been tested in a double-blind, vehicle-controlled study in humans, in terms of *in vivo* tolerability and safety [139]. According to this study, ten subjects were randomly assigned to receive either the test product or a vehicle sample cream on their arms for 28 days, while no local toxicity or irritation was observed according to the measured trans-epidermal water loss, erythema, Draize scores, and skin biopsies. Blood analysis showed no significant changes in the serum cortisol levels, indicating non-systemic toxicity. Another subsequent 6-week, randomized, double-blind, vehicle-controlled study was conducted to assess the safety and effectiveness of HC-HT CSNPs in the treatment of mild to moderate atopic dermatitis [140]. The topical use of the HC-HT CSNP cream proved to be safe when administered twice daily to the affected region. Notably, there was no significant increase in liver enzymes, indicating that the drug did not enter the systemic circulation or affect the liver [140].

According to Nunes et al. (2021), another cream beneficial for skin health containing extracts from olive oil industry by-products was developed [141]. The olive leaf extract (OLE) containing cream, which had a total phenolic content of approx. 5800 mg GAE/L, was tested *in vitro* for skin enzyme inhibition, cytotoxicity, and for antioxidant and photoprotection capacities, among others [141]. The integration of OLE into cream formulations at a 5% concentration underwent assessment for acceptability and antioxidant efficacy among 10 healthy female volunteers aged 18–65 years. No adverse reactions were noted following application of the formulations to the skin. Furthermore, the cream exhibiting the highest phenolic concentrations displayed the most significant antioxidant effectiveness [141].

Additionally, a prospective pilot study, involving 36 participants with photoaging skin reported facial rejuvenation benefits of a 1% OLE-containing cream (SUPERHEAL™ O-Live Cream, USA Patent 6743449; PhytoCeuticals, Inc, New Jersey, USA), was conducted by Wanitphakdeedecha et al. (2020) [142]. In this study, all the participants applied 0.6 g of the cream to their whole face twice daily for 2 months. The study assessed various biophysical skin properties, including melanin and erythema index, water loss, pH, texture, hydration, wrinkles, and sebum level. Improvements in wrinkles were noticeable after just 1 month of treatment, while enhancements in skin barrier function, hydration, and texture were observed after 2 months. However, despite the fact that promising findings emerged, the study had limitations, including its short duration and the absence of a control group [142].

Even though the human studies that have been published regarding the application of olive mill waste (OMW) components in cosmetics are limited, several recent preliminary studies in this field have reported promising results. In this context, some recent *in vitro* studies have demonstrated the cosmeceutical potential of hydroxytyrosol extracted from OMW, with protective effects for human dermal fibroblasts and keratocytes [143–145]. Additionally, according to another study, the effects of a phenol-rich olive mill wastewater extract (Patent 8815815) on skin cells were evaluated, and an inhibitory impact on cell proliferation as well as anti-inflammatory and anti-oxidative properties in a HaCaT (a human epidermal keratinocyte line that has been used for investigation of multistep carcinogenesis in human cells) model was reported by Schlupp et al. (2019) [146].

Another study has demonstrated that, in cell cultures, for the photoprotective potential of OLE in sunscreen formulations, used in combination with organic ultraviolet (UV) filters [147], the bioactivity of two oleuropein-enriched extracts from *O. europaea* fruits and leaves was comprehensively assessed and remarkable results regarding the antioxidant activity were observed [148].

4.4.2. Other applications in cosmetics

Hydroxytyrosol (HT), among others, has been studied extensively due to its ability to scavenge free radicals and stabilize ROS [149], which resulted in the reduction of lipid peroxidation, the enhancement of anti-inflammatory actions, and the promotion of cell proliferation [150]. Thus, HT along with oleuropein and other olive pomace polyphenols can be incorporated into emulsions and cleansing products, such as liquids, lotions, and serums.

Olive products are incorporated in several hair care cosmetic products, too. They contribute in the replacement of natural lipids, and they facilitate combing and provide shine to the hair. They form an oily phase of emulsions, and can act as over-greasing agents in detergents for the hair. They can also be found in other cosmetic formulations, such as emulsions, oils, suspensions, and gels.

As emphasized in Sections 4.4.1 and 4.4.2, there are only a few human studies examining the efficacy of olive oil by-products as bioactive ingredients in beauty products. These studies are further limited by their lack of robustness, characterized by short treatment durations (1–2 months), small sample sizes, predominantly female participants, and the absence of a control group in some cases, making them preliminary in nature. Therefore, despite the considerable potential of olive oil processing by-products in cosmetics, there is a clear need for more comprehensive research in this area.

4.4.3. The benefits of encapsulation

Unfortunately, the utilization of some olive by-products or their extracts in cosmetics may lead to several undesirable results regarding sensory characteristics. One serious problem of such applications is the stability of the extracts or the by-product itself, since phenolics, vitamin E, squalene, and some fatty acids are rather unstable compounds [151,152]. Another important issue is the smell of some bioactive compounds, which may be unpleasant for the consumers.

For all these reasons, the encapsulation of olive and olive by-products bioactives could be a promising alternative. Encapsulation is a method capable to preserve the bioactive products against oxidation, changes in environmental conditions, and interactions with other active products in the formulation, while at the same time it is an efficient way to mask their smell.

Even though data regarding the encapsulation of olive pomace bioactives are scarce, there are a few recent studies investigating the microencapsulation of olive-derived extracts for cosmetic purposes [153]. In the study of Aliakbarian et al. (2017), a method to encapsulate phenolic compounds extracted from olive pomace is presented [154]. According to the authors, the polyphenol-rich nanoparticles produced can be potentially used in the formulation of novel nutraceutical and cosmeceutical products. Panagiotopoulou et al. (2022) used microencapsulation to protect the sensitive bioactives and to favor the product's stability [155]. The aim of this study was to incorporate the microparticles into a cosmetic cream and the evaluation of several parameters, such as rheology, thermal stability, microbiological, and sensory characteristics [155]. Additionally, a study on the development of cosmetic cream formulation with polyphenols encapsulated by spray-drying with maltodextrin, aiming to incorporate them into sunscreen formulations, has also been evaluated by Galanakis et al. (2018) [65].

5. Conclusions

Olive pomace is a low-cost source of several bioactive compounds, and its valorization can reduce its environmental impact and become an additional economic resource for food industries. At the same time, industries should be more aware of sustainability issues, such as environmental degradation and the exhaustion of natural resources. The use of olive mill by-products, such as olive pomace, in the food and cosmetic sectors represents a promising way to reduce their environmental impact. Enrichment of food products with olive pomace bioactives has been extensively studied with rather positive results. On the other hand, only a few studies have been reported regarding the application of olive pomace bioactives in the cosmeceutical sector. Nowadays, cosmetics are commonly used in everyday life, and so they have a significant effect in the promotion of sustainable practices. Eco-innovation involving the utilization of raw materials, such as food industry by-products, can serve as an alternative to cosmetics. Even though olive pomace bioactives are rather promising health promoting agents, studies on their recovery, feasibility, and application in cosmetics are scarce. The anti-aging and anti-inflammatory properties of olive pomace bioactives are the key factors for its application in cosmetics, pharmaceuticals, and nutraceuticals, with the aim of improving skin protection and skin care health, among others.

All in all, the development of cosmetics with food by-products as raw materials is a rather challenging process, while aspects such as efficacy, stability, appearance, and overall acceptance from the consumers represent crucial factors for the achievement of high-quality products. Interestingly, encapsulation techniques that allow the incorporation of bioactives from several by-products in cosmetics may significantly influence their acceptance by consumers. Even though preliminary research in vitro shows rather promising effects, in vivo studies are still necessary.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

Conflict of interest

The authors declare no conflicts of interest.

Authors contributions

Conceptualization: A.T.; Methodology: A.T.; Software: All authors; Validation: A.T.; Investigation: E.P. and AT; Writing—original draft preparation: E.P. and A.T.; Writing—review and editing: All authors; Visualization: A.T.; Supervision: A.T.; Project administration: A.T. All authors have read and agreed to the published version of the manuscript.

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