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Review

Exploring Olive Pomace for Skincare Applications: A Review

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Abstract: The cosmetic industry is continuously searching for new active ingredients in an effort to attend to consumer demands which, in recent years, are focused on more natural and environmentally friendly products, obtained from sustainable resources. Nevertheless, they are required to provide cosmetologically appealing skincare products, ultimately with the purpose of improving skin appearance. The olive oil industry generates a large amount of liquid and semi-solid by-products such as olive pomace. Their phytotoxicity impairs safe disposal, so valorization strategies that promote by-product reuse are needed, which may include skincare products. Hydroxytyrosol is the main phenolic compound present in olive pomace and possesses biological effects that make it a desirable active compound for cosmetic formulations such as antioxidant and anti-aging activities as well as photoprotector, depigmenting, antimicrobial and anti-inflammatory actions. Other compounds present in olive pomace can also have functional properties and skin-related benefits. However, the application of this by-product can be a challenge in terms of formulation's design, stability, and proven efficacy, so appropriate methodologies should be used to validate its incorporation and may include extraction and further encapsulation of bioactive compounds in order to achieve effective and aesthetic appealing skincare products.

Keywords: olive oil by-products; sustainability; cosmetics; hydroxytyrosol; formulation's design

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1. Introduction

A novel economic concept, circular economy, has the ambitious purpose of expanding product lifespan, promoting recycling and re-using and closing the product lifecycle [1]. It focuses on economic and environmental sustainability, arguing that agri-food by-products are not waste, but resources to be valorized [1]. Sustainable development aims to meet the current needs of the population without compromising future generations in this process, where three interconnected dimensions have a major role: economical, environmental and social [2]. Sustainable practices can be applied to the sector of olive oil on an industrial scale. Olive tree (*Olea europaea*) cultivation is particularly widespread and increasingly relevant for the economy of countries such as Spain, Italy, Greece, and Portugal [3,4]. Extra-virgin olive oil is an important constituent of the Mediterranean diet, being known for its nutritional properties and health effects, especially against cardiovascular diseases [1,5]. These properties are due to the presence of high levels of fatty acids, particularly monounsaturated acids, as well as other valuable components such as phenolics, phytosterols, tocopherols, and squalene [5]. In fact, extra virgin olive oil contains 98% to 99% triglycerides and 1% to 2% minor components [6]. Unsaturated acids are up to 85% of olive oil composition, particularly oleic acid, whose percentage may range between 70 and 85% [6]. Unsaturated fatty acids have a particular impact as components of the lipid film on the skin surface, maintaining hydration, elasticity, as well as barrier integrity [4]. Regarding minor compounds, the most notorious representatives of this group are phenolic compounds. Lipophilic compounds with cosmetic interest such as α-tocopherol, and pigments such as carotenoids are also present in this minor group [6]. The unsaponifiable fraction of olive oil also contains squalene, a natural component of human sebum, which provides softness to the skin [4]. The emollient and protective properties of olive oil combined with great skin compatibility make it a popular ingredient in the cosmetic sector [7]. Because of its properties, olive oil can act as an active agent by itself or as an excipient of several formulations.

The olive oil industry generates high amounts of waste, particularly during the agricultural phase and oil production stage [8]. These by-products are mostly leaves, olive pomace (OP), olive stones and olive mill wastewater (OMWW) [4]. Olive oil extraction can be accomplished through discontinuous (pressing) or continuous processes (two or three-phase centrifugation) resulting in different wastes [9,10]. In the two-phase process, unlike the three-phase system, no water is used, thus being considered a more sustainable process [9]. A semi-solid residue, OP, is also produced, with different moisture content according to the method applied [10]. The water percentage can reach 70% when the two-phase process is used [10]. OP is a significant source of phenolic compounds since it retains most of the phenolic content of the olive fruit [11]. In fact, due to their chemical nature, only 1–2% of the phenolic content is found in olive oil [9,11]. On the other hand, this richness along with a low pH and high organic load makes this by-product phytotoxic and non-biodegradable [4,12]. Consequently, the disposal of these wastes encompasses an ecological concern because of their hazardous effects on soil and water [12]. As the production of olive oil is increasing, these difficulties grow to be more challenging.

As a source of phenolic compounds, OP represents a potential raw material for the manufacture of sustainable and innovative cosmetic products [12]. In fact, considering a cosmetic product life cycle, ingredient selection is of utmost importance to the final product sustainability [2]. However, more natural and sustainable ingredients can lead to formulation issues regarding performance, stability, or acceptance when compared with synthetic or commonly used alternatives [2,13].

The present work aims to review the use of olive oil by-products in cosmetic products, as well as provide evidence of OP potential in skin care considering its main phenolic compound, hydroxytyrosol. Key aspects to be considered in its incorporation in cosmetic formulations and the opportunities and challenges related will also be addressed.

2. Materials and Methods

The bibliographic search was carried out, between April 2022 and January 2023, using Science Direct, PubMed, Scopus, and Google Scholar databases using the keywords "olive" "by-products", "olive pomace" AND "cosmetic" AND "applications", as well as "hydroxytyrosol" AND "effects, "antioxidant", "antiaging", "sunscreen", "antimicrobial" or "anti-inflammatory". "Sustainability" AND "cosmetic" AND "by-products" were also searched as well as "extraction" AND "olive oil" by-products". Papers on "nanoformulations" AND cosmetic or "encapsulation" AND "olive pomace" were part of this research. Relevance, citations and publishing year were factors involved in paper selection. Books related to cosmetic technology, formulation and skin physiology were also consulted, as well as regulations on cosmetic and hygiene products.

3. Olive Oil By-Products

3.1. Olive Pomace

OP consists of olive husk and pulp, crushed olive stone and water with a moisture content of more than 60%. It is the main residue of olive oil production, representing 35–40% of the total weight of the processed olive [3,4,14]. Along with OMWW, these by-products are considered the most harmful to the environment due to their high phytotoxicity [3]. Additionally, OP contains considerable amounts of cellulose (30%) and pectic polysaccharides (39%), a rich lipid fraction, especially in oleic acid (75% lipid content), as well as squalene and a rich mineral composition [4,11]. OP is also characterized by containing antioxidants, such as tocopherols and several phenolic compounds [11]. This by-product composition is largely affected by the agronomic and technological conditions of olive oil production, including olive variety, culture cultivation, geographical origin, and extraction process [4].

3.2. Other Olive by Products: Leaves and OMWW

Olive leaves are the first by-product generated in olive oil production, in the pruning or harvesting phases and also in the olive pre-treatment cleaning step, representing 10% of the overall weight of processing olives [14,15]. A large proportion of olive leaves is underexploited or used for incineration, despite their chemical composition [15]. In fact, different compounds can be found in this matrix, which may vary according to several factors such as the selected extraction method, cultivation procedures, or climatic conditions, and include high percentages of fiber and polysaccharides, significant protein content and a wide variety of phenolic compounds [9,14,16]. Olive leaf extracts have been extensively reviewed and exhibit beneficial health effects, namely antioxidant, anti-inflammatory, hypoglycemic, anti-hypertensive, antimicrobial, anticancer, gastroprotective, and anticholesterolemic effects [16]. Additionally, cosmetic purposes have been studied due to their radical scavenging proprieties. Cádiz-Gurrea et al. [8] aimed to do a preliminary analysis of olive leaf extracts rich in oleuropein (20 and 30%) for cosmetic application. The study demonstrated that these extracts are safe for skin application after an MTT (3-[4,5-dimethylthiazol-2-yl]-2,5-diphenyltetrazolium bromide) assay in cell lines and exhibited strong antioxidant and antiradical activities. Enzyme inhibition assays of important enzymes in the aging process, showed promising results with hyaluronidase inhibition values of IC_{50} = 55 ± 1 µg/mL for the 20% extract and IC_{50} = 100.1 ± 0.8 µg/mL for the 30% extract and elastase inhibition with percentages of 19.08 ± 0.03% and 20.12 ± 0.05% at 250 µg/mL for the 20% extract and the 30% extract, respectively. Nunes et al. [3] also investigated the cosmetic potential of olive leaf extracts and their impact on formulations, with favorable results addressed in Section 5.

Olive mill oil wastewater (OMWW) is the main liquid effluent from the olive oil production process, with a red-to-black color, acidic pH and high conductivity [17,18]. Besides water, it contains sugars, organic acids, and mineral nutrients (especially potassium) and it is known to concentrate high amounts of phenolic compounds, due to their hydrosoluble nature [17]. However, these phenolic substances present phytotoxicity and biotoxicity which limits OMWW use for agriculture purposes and contributes significantly to environmental pollution, especially in the olive oil production areas [10]. Therefore, the recovery of phenolic compounds from this by-product has been proposed by several authors using extraction and membrane separation techniques, providing for safer disposal of OMWW, for example, for soil irrigation [9,18].

4. Phenolic Compounds: Hydroxytyrosol (HT) as a Cosmetic Active

Some olive bioactive components with well-known antioxidant activity are phenolic compounds [4]. Olive phenolics are greatly heterogeneous and include, mainly, phenolic alcohols (tyrosol and HT) phenolic acids (caffeic and gallic acids and verbascoside), flavonoids (luteolin, apigenin and rutin), secoiridoids (oleuropein and ligstroside) and lignans (pinoresinol) [14]. Several studies revealed that phenolic compounds possess several health benefits, such as antibacterial, antihyperlipidemic, anti-tumor, antioxidant, cardio-protective, neuroprotective, anti-hepatotoxic, or anti-diabetic properties [14,19]. Phenolic compounds are released during olive oil processing and, due to their polar character, are found in great quantities in the remains, particularly in OP and OMWW [11,20].

Numerous studies have reported the antioxidant properties of olive-related by-products in different assays such as $DPPH^{\bullet}$ (2,2-diphenyl-1-picrylhydrazyl radical) inhibition, $ABTS^{\bullet+}$ (2,2′- azino-bis 3-ethylbenzothiazoline-6-sulfonic acid) scavenging, FRAP (ferric reducing antioxidant power), TEAC (trolox equivalent antioxidant capacity), ORAC (oxygen radical absorbance capacity) and also in cell cultures and in vivo models [14].

HT, a phenolic alcohol, is the major phenolic compound present in OP, thus this by-product constitutes a major source of this bioactive molecule [11]. Among leaves, there is also a significant phenolic content with the most common compound being oleuropein [8,20]. HT is a product of oleuropein hydrolysis and has shown significant antioxidant properties [11,20]. In fact, the antioxidant capacity of HT is higher than that of other phenolic compounds with similar structures and other natural antioxidants such as vitamin C, or synthetic antioxidants such as butylated hydroxytoluene (BHT) [21,22].

Table 1 summarizes some of the most important biological activities demonstrated by HT with a dermocosmetic impact, which will be discussed in the following Sections.

Table 1. Hydroxytyrosol skin-related benefits documented in scientific literature.

Proprieties	Mechanisms
Antioxidant and anti-aging	Ability to scavenge free radicals and quelate metals [23,24]. Decrease in β-galactosidase expression [25]. Elastase and collagenase inhibition [3,25].
Anti-inflammatory	Decrease in pro-inflammatory cytokines [25]. iNOS and COX-2 inhibition [26].
Antibacterial	Reduced growth rate in Gram^{+} and Gram^{-} bacteria (e.g., *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Escherichia coli*) [27,28].
Photoprotector	Decrease in UVA-induced protein damage and proapoptotic stimulus in melanoma cells [29]. Protective effect against UVB-induced genotoxicity [30]. Protection against LED-BL skin induced damage [31].
Anti-pigmentation	Tyrosinase inhibition [32].

COX-2, cyclooxygenase-2, LED-BL, light-emitting-diode-generated blue light, iNOS, nitric oxide synthase, UVA, ultraviolet A, UVB, ultraviolet B.

4.1. Dermocosmetic Potential

4.1.1. Antioxidant, Anti-Aging and Photoprotector

Intrinsic aging is associated with the natural aging process due to physiological factors such as cellular senescence, which is triggered by oxidative stress caused by reactive oxygen species (ROS) in the dermal cells. Extrinsic aging is the result of environmental factors primarily ultraviolet (UV) radiation but also pollution or tobacco smoke. Photoaging also causes ROS production as well as transcription factors activation that mediates an inflammatory response. Additionally, proteins such as those of the extracellular matrix, intercellular lipids of the epidermal barrier and DNA are highly susceptible to damage by ROS. UV irradiation potently induces the transcription of matrix metalloproteases (MMPs) that degrade fundamental structural proteins such as collagen and elastin, leading to premature skin aging [33].

The synthesis of collagen and elastin also decreases naturally with age and, at the same time, the MMPs that degrade these proteins are up-regulated in fibroblasts and keratinocytes, an imbalance that leads to collagen and elastin deficiency, translated in visible signs, such as loss of skin cohesiveness, elasticity and wrinkles [33].

The cosmetic industry is searching for natural compounds and extracts with antioxidant potential to use as ingredients for their formulations and develop novel products that could delay the signs of aging. These anti-aging ingredients can act through one or more different mechanisms, such as providing a moisturizing effect, promoting cell renewal or repair, exhibiting anti-oxidant action, inhibiting MMPs and preventing photoaging [33].

A study conducted by Rietjens et al. [24] has shown high scavenging activities of HT towards superoxide anions, hydroxyl and peroxynitrite radicals, but not hydrogen peroxide, as seen in previous studies. The antioxidant efficiency of this phenolic substance is mainly attributed to the ortho-dihydroxyphenolic structure which can donate the hydrogen atom to ROS [17].

HT properties have been investigated in the prevention and treatment of UV-mediated skin damage. Jeon and Choi [25] demonstrated that HT lowered β-galactosidase activity, a senescence indicator, in a dose-dependent manner on UVA-exposed human dermal fibroblasts (HDFs) and reduced the expression of MMP-1 and MMP-3 induced by UVA radiation. In this study, HT also exhibited anti-inflammatory activity with the decreased expression of IL-1β, IL-6 and IL-8 genes in HDFs cells after UVA exposure.

Another study assessed HT photoprotector ability in different concentrations (25, 50, and 100 μM), concerning UVB radiation effects in HaCaT keratinocytes [30]. ROS formation, induced by UVB treatment, was prevented by HT with 47% scavenging activity at the higher concentration tested (100 μM). DNA damage was assessed using the comet assay, and HT was shown to have a significant protective effect against UVB genotoxicity at 100 μM. Additionally, at the higher concentration, HT was able to decrease 8-hydroxy-2′-deoxyguanosine (8-OHdG) levels, an adduct product that is indicative of oxidatively damaged DNA formed by ROS [30]. In another work using melanoma cells subjected to UVA radiation, HT prevented the uprise of typical markers of oxidative stress and protein damage, in a dose-dependent manner [29].

Recent studies have shown the impact of light-emitting-diode-generated blue light (LED-BL) on skin structure, related to the increasing use of digital devices such as computers, tablets smartphones and other gadgets [31]. Avola et al. [31] demonstrated that HT at 10, 25, and 50 μg/mL concentrations had a protective effect, in a dose-dependent manner, in skin keratinocytes and fibroblasts subjected to LED-BL damage, by decreasing ROS formation and MMP-1 and MMP-12 levels, preserving collagen type I production and reducing 8-OHdG formation.

4.1.2. Anti-Inflammatory

Maiuri et al. [26] presented a study in which HT at 200 μM was capable of inhibiting the protein expression of two mediator enzymes of the inflammatory response, nitric oxide synthase (iNOS) and cyclooxygenase-2 (COX-2), in J774 murine macrophages, stimulated with lipopolysaccharide (LPS).

There is also evidence that its use in topic formulations or nutraceuticals could benefit inflammatory pathologies such as atopic dermatitis or psoriasis [34,35]. In vivo anti-inflammatory results could be observed after treatment with a nutraceutical, Alyvium® (Solvitae Medica, Madrid, Spain) which contains 500 mg of an olive polyphenolic extract, in patients with mild to moderate psoriasis. In a three-month period, patients experienced improved cutaneous manifestations as well as a 25% affected area and severity index reduction [34]. As for the topical anti-inflammatory effect, an HT-based formulation conveyed in its natural vehicle, extra virgin oil (Fenolia® Eudermal Cream 15, P&P Farma, Turin, Italy), was shown to prevent inflammation and repair the skin, in the reconstructed human epidermis (RHE), suggesting it might be potentially effective in mild to moderate atopic dermatitis. A decrease of 42.30% and 45.97% of IL-1α and IL-8, respectively, was observed and it was superior to the reference drug dexamethasone [35]. The tolerability and safety of an association between HT and a topical glucocorticoid were also assessed in vivo with good results [36]. Chitosan nanoparticles with HT and hydrocortisone formulation stability, skin tolerability and systemic safety was assessed with satisfactory results. Application for 28 days in healthy volunteers demonstrated effective results, through non-invasive techniques, with no signs of irritation or erythema, making it a preliminary study for the possible topical treatment of atopic dermatitis [36].

4.1.3. Antimicrobial

Regarding antimicrobial activity, studies have not been consensual. In 1999, Bisignano and colleagues reported the antimicrobial activity of HT showing that low concentrations effectively inhibit the growth of several bacterial strains in the American Type Culture Collection (ATCC) [27]. However, Medina-Martinez et al. [37] had significantly different results demonstrating that culture media and bacterial strains can affect the antimicrobial results of HT. In a recent study, by Nunes et al. [28], OP extracts from different geographical origins were characterized and tested for antimicrobial activity. Although HT content influenced the results, (the sample that presented the highest content of HT, 220 mg/100 g, also had the best minimal inhibitory concentration (MIC) for *Escherichia coli*, 62.5 mg/mL) a synergistic effect among all the phenolics and other compounds is more likely to account to this biological action. Additionally, Ghalandari et al. [38] revealed HT antimicrobial activity against *Staphylococcus aureus* and *Staphylococcus epidermidis* with MIC values of 3.125 mg/mL and 6.25 mg/mL, respectively.

Crisante et al. [39] synthesized an HT-based polyacrylate and further analyzed its anti-biofilm and antibacterial activity against *Staphylococcus epidermidis*. The results indicated that this HT-polymer reduced bacterial adhesion compared to the control which might suggest its potential in biofilm-based infection prevention or treatment, particularly in hospital settings [40].

Given the antibacterial activity shown by olive oil by-products and their powerful antioxidant effect, they could be seen as alternative preservatives in cosmetic formulations, in addition, or in substitution for synthetic ones [3]. The search for new and natural antioxidants to replace synthetic ones has increased in the last few years, since many are strictly regulated due to safety reasons.

HT's role in wound healing has also been a subject of interest. Cells produce ROS to protect against the invasion of microorganisms; however, overproduction of ROS and prolonged inflammation can lower the rate of wound healing [41]. An extract of olive fruit and leaves rich in HT and oleuropein (Olivamine®, McCord Research, Iowa, IA, USA) accelerated the restoration of damaged endothelial culture cells by increasing levels of growth factors and doubling the proliferation of epithelial cells. This study also revealed that individually, HT and oleuropein were less effective, suggesting phenolic compounds are more active when administered as an extract rather than used in their purified form [41].

4.1.4. Depigmentant

HT also influences tyrosinase activity, an enzyme involved in melanin production, reducing its activity [32]. In this study, HT presented similar results to a known depigmenting agent, kojic acid, against mushroom tyrosinase, with an IC_{50} value of 13 μmol/L versus 14.8 μmol/L. Codina and Monjo patented a method to produce a dermocosmetic containing an olive extract with 40% HT to inhibit melanin synthesis, acting as a depigmenting agent, with in vivo skin compatibility [42].

5. Applications of Olive Oil By-Products in the Cosmetic Industry

Despite the high number of olive-based cosmetic products on the market, such as moisturizers or cleansers with emollient, hydrating and antioxidant claims, there is limited work regarding the use of by-products in topical formulations. A literature review suggests there are few cosmetics developed based on olive leaves or OMWW extracts, and some already commercialized extracts, but to the best of our knowledge, there are no olive pomace-based topic formulations.

5.1. Antioxidant and Anti-Aging

The anti-aging market is continually growing and, considering the characteristics of olive oil by-products, their potential use in cosmetic formulations is extremely relevant.

Nunes et al. [3] developed oil-in-water (O/W) creams incorporating olive leaves extracts (5%) with promising results: no skin or eye irritation, in vivo skin compatibility and acceptability, antioxidant and antimicrobial activity, inhibition of elastase and photoprotection ability. Safety analysis methods included MTT and skin irritation assays using Human Corneal Epithelium and Reconstructed Human Epidermis (RHE) models SkinEthic™ HCE and EpiSkin™ (Lyon, France), respectively, and repeated applications of the samples under an occlusive patch for an in vivo irritation study with 51 volunteers.

Wanitphakdeedecha et al. [43] conducted a study with 36 volunteers to assess the improvement of photoaged skin after the application of an olive leave extract base cream (SUPERHEAL® O-live cream, PhytoCeuticals Inc., Hawthorne, NJ, USA). The texture and wrinkles of the skin were evaluated by using a UVA light video camera, Visioscan® VC 98 (Courage & Khazaka Electronic GmbH, Köln, Germany) and other biometric parameters using a MultiProbe Adapter System® (Courage & Khazaka Electronic GmbH, Köln, Germany). After two months, the results revealed a decrease in transepidermal water loss (TEWL) and an improvement in skin texture and hydration, as well as a reduction in hyperpigmented spots and wrinkles. TEWL measurements allow for the parametric evaluation of the effect of barrier creams since it relates to the outward diffusion of water through the skin [33]. Hence, a decrease in the skin's TEWL reflects an enhanced ability to retain moisture. Volunteer acceptance was also evaluated in this study stating that odor and color were not agreeable. Besides, this work had some limitations, since it was a pilot study no control group was used, and ceramide was one of the formulation ingredients which could also have influenced the results [43].

5.2. Photoprotector

Antioxidants are typically used in sunscreens to complement UV filter protection, as they can reduce the damage induced by ROS generated by solar irradiation [44]. Recovery of phenolic compounds from OMWW was applied in different sunscreen formulations by Galanakis et al. [44]. An amount of 200 mg olive phenols powder was emulsified with 25 g base cream and the encapsulation of olive phenols in silica particles and/or the liposome effect on water resistance was tested. The higher water resistance (73%) was observed after the adsorption of olive phenols in silica particles and their emulsification in a base cream. Solutions with olive phenols extracted from OMWW with concentrations between 2.5 and 15 mg/L of olive phenols were combined with physical and chemical filters to evaluate the potential UV booster effect through in vitro sun protection factor (SPF) testing. The results confirmed OMWW photoprotector activity since the SPF value of the UV filter solutions increased linearly for all the tested phenolic concentrations [44]. Another study from Galanakis and colleagues [45] has shown UVA and UVB absorbance in OMWW formulations, and olive phenolics are more active UV filters in a broader region of UVB and UVA compared to ascorbic acid and α-tocopherol, promoting its use as a booster for chemical filters commonly used. Since many chemical sunscreen agents induce photo irritation and photosensitization, reducing their concentration by adding an SPF booster could improve the formulation tolerance without affecting their properties [46].

Table 2 reviews the cosmetic applications of olive oil by-products found in the literature.

Table 2. Cosmetic application of olive oil by-products.

By-Product	Formulation	Accomplishments	Limitations	References
Olive leaves extract	O/W creams	No skin or eye irritation In vivo skin compatibility Antioxidant activity Elastase inhibition Photoprotection Antimicrobial activity	Emulsion instability	[3]
OMWW	Sunscreens with and without encapsulation	UV booster capacity	Without encapsulation olive phenolics are not water resistant. Silica particles addition resulted in a more viscous cream	[44]
Olive leaves extract	SUPERHEAL™ O-Live Cream	TEWL decreased Skin hydration increased Skin texture improvement Hyperpigmented spots reduced	Mild acneiform eruption (16.7%) Odor and color found unpleasant	[43]

O/W, oil-in-water, TEWL, transepidermal water loss, UV, ultraviolet.

6. Olive Pomace as a Potential Cosmetic Ingredient

6.1. Formulation's Design

The development of a new cosmetic product must consider not only technical and regulatory requirements but also market placement and consumer demand [47]. In fact, natural products and sustainability have been, in recent years, a focus in the cosmetic industry driven by more eco-conscious consumers. However, formulating cosmetics with plant-based actives can represent technical challenges as well as quality, safety, and efficacy concerns [47]. Stability, skin bioavailability and effective concentrations of antioxidants are important when including them in topical formulations [33]. Additionally, it is important to find the right balance between rheological behavior, which impacts consumer use, acceptability and formulation stability, and the concentration of active ingredients needed to demonstrate efficacy [47].

6.1.1. Extracts versus Isolated Compounds

Many natural ingredients may have more than one predominantly active compound with various biochemical actions, and this complexity can be very appealing, rather than the use of a purified component. On the other hand, complex extracts may cause difficulties in formulation, as well as problems with formula stability [48].

OP extracts offer a variety of interesting cosmetic ingredients and synergistic effects that are also to be considered since the interaction within phenolics or between phenolics and other antioxidants could potentiate their activity [49].

Numerous studies have reported the extraction of bioactive compounds from OP (Table 3). The extraction of these compounds can be performed by using conventional or non-conventional extraction methods [14,16]. The increasing need for the use of more efficient recovery processes has led to the development of non-conventional methods that can reduce the extraction time as well as solvent and energy consumption when compared to conventional extraction methodologies [18]. In that sense, non-conventional techniques, such as ultrasound-assisted extraction, microwave-assisted extraction, pressurized liquid extraction and supercritical fluid extraction have been used in order to improve the extraction yield of phenolic compounds [21]. The use of eco-friendly and dermal-safe solvents such as water, ethanol or a natural deep eutectic solvent (NADES) complies with green chemistry principles and contributes to the cosmetic product's final sustainability [50]. In order to maximize the extraction process, parameters including sample preparation extraction time, temperature, solvent and solid-to-liquid ratio (SLR), are frequently optimized [51].

For cosmetic purposes and allegation claims these extracts should be standardized to ensure a known concentration of the primary active compound, such as HT. Additionally, bioassays can be used to determine biological activities within the extract, such as enzyme activity [48].

From a circular economy perspective, phenolics extraction allows for the reminiscent solid phase, free of phytotoxic compounds, to be used as an agricultural substrate for crop production, no longer representing an environmental burden [52].

Table 3. Different extraction methods applied to OP.

Method	Optimum Extraction Conditions	Results	References
Solid-liquid extraction	OP pressing followed by aqueous extraction of the solid phase (SLR 1:40 for 2 h at 40 °C) and reverse osmosis membrane concentration	TPC: 1234.3 ± 54.0 mg_{GAE}/L	[52]
Ultrasound-assisted extraction	SLR: 1:50 (g/mL) Water 20 KHz 160 W 5 min at 25 °C	TPC: 402 $\mu g_{GAE}/mL$, HT: 238.42 ± 35.90 mg/100 g	[11]
	2 g/100 mL of water 250 W power 75 min at 30 °C	TPC: 19.71 ± 1.41 mg_{GAE}/g	[53]
	SLR: 1:30 (g/mL) 90% ethanol 20 kHz 5 min at 50 °C	HT: 55.11 ± 2.14 mg/g	[54]

Table 3. *Cont.*

Method	Optimum Extraction Conditions	Results	References
	SLR: 1:12.5 (g/mL) NADES (Choline chloride-caffeic acid) 280 W 60 kHz 30 min at 60 °C	TPC: 20.14 mg_{GAE}/g dw HT: 1.05 mg/g dw	[50]
Microwave assisted extraction	SLR: 1:15 (g/mL) 100% ethanol 600 W 17 min at 35–60 °C	HT: 128.4 ± 0.3 mg/kg	[55]
	SLR: 1:12.5 (g/mL) NADES (choline chloride-lactic acid) 200 W 30 min at 60 °C	TPC: 29.57 mg_{GAE}/g dw HT: 0.89 mg/g dw	[50]
	SLR: 1:30 (g/mL) 90% ethanol 600 W 5 min at 50 °C	HT: 53.2 ± 1.59 mg/g	[54]
	SLR: 1:15 (g/mL) 2.0% enzyme (cellulase pectinase, tannase) 600 W 17 min at 60 °C	TPC: 341 mg_{GAE}/g	[55]
Supercritical fluid extraction	SLR: 1:3 CO_2 + 60% ethanol 300 bar 60 min at 50 °C	TPC: 14.01 ± 0.31 mg_{GAE}/g, HT: 1.25 ± 0.01 mg/g	[56]
Pressurized liquid extraction	Supercritical CO_2 pre-treatment 0.8 $g_{OP}/mL_{SOLVENT}$ 90% ethanol 184.0 °C	TPC: 340 mg_{GAE}/g dw HT: 9.5 mg/g dw	[57]

dw, dry weight, GAE, gallic acid equivalents, HT, hydroxytyrosol, NADES, natural deep eutectic solvent, OP, olive pomace, TPC, total phenolics content, SLR, solid to liquid ratio.

6.1.2. Olive Pomace Powders

Besides phenolics, other compounds can be incorporated into cosmetic formulations due to their chemical proprieties by improving sensory characteristics, such as texture or viscosity, or promoting hydration and skin protection [4]. Monosaturated fatty acids provide structural stability to cell membranes, squalene has emollient qualities as well as an effect as a skin barrier against solar rays and antioxidant proprieties, and minerals are part of the natural moisturizing factor, and essential to the stratum corneum hydration plasticity and homeostasis [4].

Fractionation approaches could also be an advantage to obtain different value-added products from OP. Ribeiro et al. [58] used centrifugation to separate the liquid from the solid fraction, followed by freeze-drying. The dry fraction was then sieved after a previous milling process, thus obtaining the pulp fraction and the stones fraction. Chemical composition analysis showed that fiber is the most abundant component in the pulp fraction also exhibiting a significant amount of protein (8–9% dry weight (dw)) and fat (15–21% dw). Antioxidant activity was evaluated using three different methods ($DPPH^{\bullet}$, $ABTS^{\bullet+}$ and ORAC) and presented higher values in the liquid fraction in all methods, related to the higher recovery of phenolic compounds such as HT. Minerals were also mostly present in the liquid fraction. Nevertheless, the pulp fraction possesses phenolic compounds mainly bound to fiber. In a different study, this fraction showed functional proprieties such as water-holding capacity which can be interesting in skin care products providing moisturizing effects in a variety of cosmetics [59]. On the other hand, fiber content can increase emulsion stability by improving viscosity [60]. In the same study, the liquid fraction demonstrated antimicrobial activity which may be attributed to the presence of higher amounts of organic acids such as formic, lactic and acetic acids, besides the higher concentration of phenolics [59]. This fraction could act as an antioxidant active with potential self -preservative actions in cosmetic formulations. Cytotoxicity and mutagenicity of the powdered fraction were also assessed showing a good safety profile [59].

6.1.3. Encapsulation Strategies

Despite their benefits, phenolic compounds show low stability in environmental conditions such as exposure to light, oxygen, temperature and enzymatic activities [61].

Encapsulation strategies are being constantly developed in order to face limitations in the incorporation of certain active substances, such as bioavailability or stability issues and can also improve active the compound's physicochemical characteristics or provide controlled release [62,63]. Encapsulation can also enhance bioactive skin penetration in addition to solving potential organoleptic constraints [62]. In fact, natural products, such as olive pomace, can present a color that, if unmasked, can affect consumer acceptance of the cosmetic product.

It is well-recognized that encapsulation can minimize phenolic instability and provide better formulations with an improvement in product shelf-life [44]. Kesente et al. [64] encapsulated olive leaf extract in biodegradable polylactic acid nanoparticles. These nanoparticles were characterized considering particle size, polydispersity index, zeta potential, in vitro phenolics release, and encapsulation efficiency. The loaded nanoparticles were incorporated in a cosmetic formulation and the stability of the formulation was studied for a three-month period using freeze cycles as well as storage at 5, 25 and 40 °C. The nanoparticles showed an adequate particle size and homogenous nanoparticle population with an encapsulation efficiency of 49.2%. The cosmetic formulation also demonstrated increased stability compared to the pure extract with respect to viscosity, pH and organoleptic characteristics.

Other strategies, such as the development of more lipophilic HT-derivates, can provide an increase in percutaneous absorption, maintaining antioxidant proprieties [65].

Regarding HT-based sunscreen use, water immersion can lead to skin HT removal due to its hydrosoluble nature, so strategies to promote water resistance are essential [44]. Complexation of HT with β-cyclodextrins or the addition of silica particles could be a way to improve its efficacy [44,63]. López García et al. [63] studied the complexation of HT with β-cyclodextrin and hydroxypropyl-β-cyclodextrin and the results suggested that complexation enhances HT photostability thus allowing a more prolonged antioxidant activity.

The encapsulation methods applied for phenolic-rich extracts described in the literature for OP regard microencapsulation [10].

The microencapsulation technique is a process in which micro-sized particles are coated with an encapsulating agent followed by a drying process [66]. In personal care formulations, microencapsulation can improve aesthetics, and stability and increase the shelf life of the finished product [67].

Paini et al. [61] encapsulated a phenolic compound extracted from OP, by spray drying, using maltodextrin as a coating agent at different concentrations. The spray-drying technique is based on the atomization of a liquid formulation in hot air, producing a final product in powder form, which improves microbiological stability, enhances water solubility and reduces degradation mechanisms [61,66]. The impact of parameters such as inlet temperature and feed flow was evaluated in this work [61]. Spray drying at an inlet temperature of 130 °C, maltodextrin concentration of 100 g/L and feed flow of 10 mL/min, resulted in the highest microencapsulation yield (94%), encapsulation efficiency (76%) and polyphenols content (39.5 mg_{CAE}/g dry OP). Stability at different temperatures and light conditions for 70 days was also assessed. A reduction of 21% and 34% of the initial phenolic content was observed for the samples stored at 25 °C and 45 °C, respectively. Sunlight also impacted stability with phenolic content decreasing from 40.0 ± 4.0 mg_{CAE}/g dry OP to 33.1 ± 0.8 mg_{CAE}/g dry OP in 14 days.

The microencapsulation of phenolic compounds from OP has also been performed by applying the freeze-drying technique. Chianoti et al. [66] encapsulated phenolic extracts with maltodextrin as a coating agent by freeze-drying. The final encapsulated product presented increased stability, improved hygroscopicity, water solubility, and antioxidant activity, and high encapsulation efficiency (82–90%) [66].

Another study by Cepo et al. [68] encapsulated phenolic compounds from OP using cyclodextrin as an agent and a spray-drying method. Encapsulated phenolic antioxidant activity was assessed in different biological models and food matrices and compared with the synthetic antioxidant butylated hydroxyanisole (BHA). Cyclodextrin encapsulation enhanced the antioxidant activity of OP extracts by significantly increasing their polyphenolic content. Their antioxidant activity in the oil and meat models was comparable to that of BHA when applied at concentration levels of 0.1% and 2–3%, respectively.

Although some of these studies regard the incorporation of encapsulated phenolics in food matrices the same encapsulation principles can be applied to cosmetic formulations, bearing in mind stability and shelf life, toxicity, skin permeation and organoleptic attributes.

Nanoformulations, such as nanoparticles or nanoemulsions, are a growing market in cosmetics as they allow an enhanced delivery of active compounds [69]. Aging affects the dermal layer of the skin leading to collagen and elastin breakdown. Nanoformulations possess the potential to penetrate the deeper layers of the skin which can be advantageous to increase active concentration and promote anti-aging efficiency [70]. This capacity can advocate for cosmeceutical application. Cosmeceuticals fall in a category between cosmetic products and medicines, providing clinically meaningful effects, and are increasingly popular in the cosmetic sector, particularly in the anti-aging category [48,71]. Generally, the use of the nanoemulsions for encapsulation of natural antioxidants is considered a more promising approach due to its advantage over other encapsulation techniques [66]. Nanoemulsions possess pleasant visual characteristics and skin feeling upon application, along with improved stability compared to conventional emulsions [71]. Due to the low amount of surfactant, they usually require high-energy input methodologies to guarantee stability, requiring expensive equipment that is not always available at the production scale [69].

6.2. Quality Control

6.2.1. Safety

For the most part, natural ingredients present a composition that is difficult to control and has low stability in terms of color and activity. Another concern is the possibility of contamination with chemicals such as heavy metals and other pernicious toxins for human health [72]. Therefore, it is imperative to assess the safety of plant-derived ingredients in cosmetic and hygiene products considering the phytochemical characterization of the source, and information regarding contamination, adulteration, or hazardous residues [73]. Toxicity assays should be performed in order to avoid the presence of irritant constituents and the cytotoxicity of these compounds can be evaluated using MTT and lactate dehydrogenase (LDH) assays in cell lines as well as in vitro models to test skin or eye irritation [4]. RHE, such as EpiSkin^{TM} or SkinEthic^{TM}, consists of multilayered epithelium cultured in a chemically defined medium mimicking the biophysical properties of in vivo human epidermis [62]. These models are able to determine cell viability (MTT assay), histology, and pro-inflammatory mediators release, but have some limitations as they show a difference in the lipid organization and as a consequence higher relative permeability [62]. To complement this approach, in vivo assays, such as the human repeat insult patch test (HRIPT) should also be conducted to evaluate acute irritant reactions in human volunteers [48]. In vitro testing of percutaneous absorption/penetration may also be of importance, especially for the evaluation of sensitization and systemic risks [74].

6.2.2. Stability

Stability testing ensures that a cosmetic product meets the intended physical, chemical, and microbiological quality standards, as well as functionality and aesthetics when stored under appropriate conditions. To study these effects, stability tests are mostly performed in accelerated or stress conditions and evaluated parameters include color, odor and appearance, pH, viscosity, weight changes and microbial contamination [75]. In fact, the incorporation of the extracts can influence the internal structure of an emulsion as shown by Nunes et al. [3]. Rheology offers a methodological approach to optimize cosmetic formulations, enhancing stability, and pH should be compatible with dermal use (about 5–6) during storage and in-use [47]. In addition, when encapsulation methods are applied, various characterization techniques should be employed to evaluate the phenolics-loaded systems. Droplet size and zeta potential provide information regarding physical stability. Cytotoxicity (in vitro/in vivo), phenolic release, and antioxidant activity are also parameters that are imperative to address since they impact the safety and presume the efficacy of the delivery system [69,76].

6.2.3. Efficacy

Cosmetic product claims are subject to a framework of regulation and should be evidence-based and not misleading [77]. Most claims can be substantiated through efficacy tests such as instrumental methodologies, clinical and perceived efficacy or consumer studies [71]. Instrumental measurements are made on subjects in controlled laboratory conditions/environment and comprise some already mentioned in this work as hydration, roughness, firmness, and elasticity of the skin among others [33]. Sensory analysis is an extremely useful and relevant tool for developing cosmetic products that meet the consumer's expectations [13,71]. Additionally, it can help assess the impact of ingredient or production process variations and collect useful information to optimize cosmetic formula compliance [71]. Sensory analysis such as in-use tests with self-evaluation by consumers, sensory tests with trained expert panels or controlled clinical testing conducted by a qualified professional are accepted methodologies to provide claims evidence [77].

7. Challenges and Opportunities

7.1. Sustainability

The use of natural ingredients has been drawing significant attention in recent years since they are generally considered safe, with multiple biological activities, cost-effective and can be obtained from renewable sources [46]. Additionally, from a consumer perspective, they are more desirable than synthetic alternatives. The cosmetic industry is a fast-paced market that continuously thrives for innovative ingredients and formulations, to attend to a more informed, environmentally aware and assertive consumer. However, natural does not necessarily mean sustainable and one of the main challenges is the replacement of unsustainable ingredients for sustainable ones, encouraging the use of by-products [2]. This approach can overcome ecological concerns of by-product disposal, provide economic benefits and simultaneously appraise raw materials that have undoubted biological actions. Nevertheless, the recovery of by-products in the food industries may require the incorporation of new procedures and equipment, meaning an increase in costs which can be unacceptable for small industries [14].

7.2. Reproducibility and Scale Up

A summary of the opportunities and challenges in by-product use is presented in Table 4.

Table 4. Opportunities and challenges in the use of olive pomace.

Opportunities	Challenges
Overcoming environmental issues regarding disposal	Stability: thermal and light-induced decomposition could limit shelf-life
Consumers demand for natural and sustainable products	Formulation may require strategies to promote efficacy and organoleptic qualities
Biological activities	Natural products associated variability
Cosmetic regulation allows the incorporation of these ingredients	OP is produced in a limited time period along the year (seasonal)
Extracts have a multiplicity of compounds with cosmetic interest	Results observed in in vitro skin models but not in vivo on a sufficient number of human subjects.

Effective concentrations of active substances in vivo are essential to cosmetic claims [62]. Their efficacy in skincare products is determined by in vitro and in vivo testing considering the type of dermatological into which they are incorporated [78]. Natural products can face a high variability in their chemical composition, according to their extractive method or, as mentioned before, processing conditions. This can influence biological activities and formulation reproducibility so more studies on the finished product are needed.

Another challenge in OP application is that its production occurs in a limited time period and this by-product is easily susceptible to microbial degradation due to its high moisture content. Therefore, constraints in raw material availability, especially when considering upscaling need to be considered. Methodologies that reduce raw material microbial count should also be considered and evaluated for their impact on bioactive composition. Additionally, a cost-benefit analysis must be established to scale up at the industrial level when choosing an extraction method, which can influence the feasibility of cosmetic development [18].

8. Conclusions

Society has become concerned with sustainability issues such as natural resource depletion or environmental degradation and expects key industry players to become more aware and socially responsible. Cosmetic products play an essential role in everyday life so their impact in endorsing sustainable practices is considerable. Eco-innovation with the selection of raw materials such as agri-food by-products can present an alternative to skincare products. Olive pomace is considered to be a low-cost and renewable source of high-added value compounds and its valorization can generate an additional economic resource for agri-food industries and mitigate its environmental burden. Despite the promising potential of OP as a source of phenolic compounds, only a few studies have examined the feasibility of their recovery and application. Anti-aging skincare could be a potential market for this raw material, both in topical formulations or nutraceuticals that could enhance skin protection against oxidative stress. Additionally, studies regarding its anti-inflammatory activity in skin disorders can promote its application in formulations designed to improve cutaneous health, complementing pharmacological approaches.

Designing cosmetics with agri-food waste is a new trend and can be quite challenging. Aspects such as stability, appearance and efficacy need to be validated in order to achieve quality skin care products. Some strategies such as non-conventional extraction methods or encapsulation techniques, as well as analytical procedures that allow a new ingredient chemical characterization and toxicological assessment, are of utmost importance. Incorporation in cosmetic formulations can influence their acceptance by consumers and impact overall stability. Moreover, even though preliminary research in vitro shows promising effects, in vivo validation is still necessary.

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