

Review

Byproducts as a Sustainable Source of Cosmetic Ingredients

Manuela Machado , Sara Silva * and Eduardo M. Costa 

Universidade Católica Portuguesa, CBQF—Centro de Biotecnologia e Química Fina—Laboratório Associado, Escola Superior de Biotecnologia, Rua Diogo Botelho 1327, 4169-005 Porto, Portugal; mmachado@ucp.pt (M.M.); emcosta@ucp.pt (E.M.C.)

* Correspondence: snsilva@ucp.pt

Abstract: The cosmetic industry has been driven to implement sustainable practices that can help it overcome its high carbon footprint and intensive raw material extraction needs. The adoption of circular economy and bioeconomy concepts within the industry has been regarded as a solution for this problem, and within these concepts, byproducts' incorporation in the cosmetics production chain, either as bioactive or as a structural component, is only a logical step. With this in mind, this review aims to provide an overarching view of the application of byproducts in cosmetics with emphasis not only on their potential biological properties but also on all the regulations and societal and economic impacts associated with byproducts' incorporation into cosmetics and how they can help this industry.

Keywords: byproducts; cosmetics; plant; bioactivity; sustainability

1. Introduction

Consumer awareness of environmental impact and sustainability has significantly influenced the market, leading to a noticeable change in the consumption of green products, particularly within the Asian–Pacific region [1]. This shift is driven by various external factors that contribute to changing consumer behavior, such as heightened awareness of green consumerism, evolving marketing trends, and cultural and social influences, such as normative beliefs and the roles of social groups. In addition, personal factors, including age, life stage, wealth, and even religious beliefs, also play a pivotal role in determining the extent of a consumer's commitment to environmentally friendly products [1,2].

For the cosmetic industry, the rising consumer demand for sustainability and green solutions created two challenges to be solved. The first is the incorporation of natural compounds in products, thus responding to consumer demands for greener and more natural products, and the adjustment required during the production process for this to occur. The second, and the one which represents a more radical shift for the cosmetics industry, is the need to find new and sustainable sources of bioactive natural compounds. With this need and companies pushing knowledge boundaries in the search for new and sustainable sources of compounds, one solution emerged: byproducts [3,4].

Byproducts are, by definition, incidental or secondary products of the manufacture process and were once considered as wastes or residues without any added value, but nowadays they are considered secondary sources of bioactive and technological relevant compounds. In the context of sustainability, byproducts have gained significant importance as they are now key contributors to various industries, including cosmetics, due to their sustainability, green credentials, and effective role in diminishing primary industries' footprint and wastes [5,6]. The increased presence and utilization of byproducts-derived compounds is seen as a key contributor to the future sustainable development of industries, especially in terms of reducing their environmental impact, with its relevance being formalized on a global level by the UN with its 2030 Agent for Sustainable Development, particularly in the responsible consumption and production goals [6]. For the cosmetic industry in particular,



Citation: Machado, M.; Silva, S.; Costa, E.M. Byproducts as a Sustainable Source of Cosmetic Ingredients. *Appl. Sci.* **2024**, *14*, 10241. <https://doi.org/10.3390/app142210241>

Received: 19 September 2024

Revised: 4 November 2024

Accepted: 5 November 2024

Published: 7 November 2024



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the use of byproducts-derived compounds will be of great importance and benefit, as their introduction will contribute substantially to the industry's sustainability drive and goals. Through the minimization of the waste generated and the reduction in the industries' reliance on new raw materials, the overall environmental impact of the cosmetics sector will be lessened, and byproducts will become a cornerstone in the development of future sustainable cosmetics [7]. Considering the inherent complexity of byproducts-derived compounds' incorporation into cosmetics, this review aims to provide an encompassing visualization of byproducts of animal and plant sources from which ingredients can be extracted and which can be used or are already in use in cosmetics, advantages of their incorporation, and the various additional considerations, such as applicable legislation and consumer awareness, that have to be taken into account on this topic.

2. Byproducts in Cosmetics

When considering byproducts for cosmetic applications, the most commonly utilized sources are agro-food, marine, and forestry-based industries, as these sectors are significant producers of biologically active byproducts that can be repurposed due to their bioactive properties [6]. The byproducts derived from these sources can be usually organized in two main categories: animal based and plant based.

2.1. Animal Byproducts

The main contributors in this category are the fisheries and meat industries. The former includes fish, crustaceans, and other aquatic animals (but not algae) and is credited with its byproducts accounting for almost 55% to 65% of each year in catch dry weight. Considering that the Food and Agriculture Organization (FAO) estimated that in 2020 over 214 million tons of seafood were produced, one can estimate that roughly 139.1 million tons (65% of total weight) of fisheries byproducts were produced in this year alone [8,9]. This weight can be mainly attributed to three distinct sources: fish, crustaceans, and molluscs. Heads, intestine, skin, bones, and scales are the byproducts obtained from fish processing, and derived from them are bioactive peptides, collagen, gelatin, fish oil, and calcium phosphates. From crustacean, carapaces and heads are the products generated, and the main compounds obtained are calcium carbonate, chitin, chitosan, protein, and astaxanthin. Lastly, from molluscs, the shell is the byproduct produced and can account for up to 90% of its weight, and proteins, polysaccharides, and calcium are the main compounds obtained [10–14]. The main applications and products produced with these byproducts can be found in Table 1.

Table 1. Fish byproducts' main cosmetic-related applications. PUFA: polyunsaturated fatty acids; MMP-1: matrix metalloproteinase-1.

Source	Byproduct Example	Compounds Extracted	Application	Types of Products	References
Fish	Skins, intestines and scales.	Collagen and its peptides, gelatin.	Skin elasticity, moisturizing and wound healing.	Face creams, body lotions, shampoos, sunscreens and oral supplement.	[15–18]
	Fish off-cuts (skin with stuck muscle).	Oil rich in PUFA.	Skin reaction to UV, acne decrease, MMP-1 production inhibition.	Oral supplement.	[19–21]
	Fish bones.	Natural calcium phosphates.	UV protection.	Sun cream and hydrogels.	[22,23]
Crustaceans	Carapaces.	Chitin and chitosan.	Delivery systems of active compounds, structural component and antimicrobial.	Sunscreens, cosmetic mask, shampoo.	[24–26]

Table 1. Cont.

Source	Byproduct Example	Compounds Extracted	Application	Types of Products	References
	Heads, shells, tails.	Astaxanthin.	UV protection, antiaging, moisturizer.	Oral supplement, creams and films.	[27–29]
Mollusc	Shell.	Powdered or extracts from shells.	Collagen type I and II synthesis.	Cream.	[30]

When considering examples of the applications given in Table 1, one question stands out. How are the referenced materials attained? In the literature, various examples can be found for the different categories considered. For fish byproducts, one can consider the work of Dănilă, Stan [31] in which, through a combination of acid and alkaline treatments with an autoclave (pressure and temperature)-based extraction, collagen hydrolysates were attained from Romanian carp skin. When talking about crustaceans, a clear example is the chitin and chitosan extraction procedure from these animals' byproducts (namely, shells) through alkaline extraction with NaOH, a process which is normally milder (less temperature, NaOH, or time) than the traditional extraction from animals [32]. For molluscs, traditionally, their shells are thermically treated (up to 500 °C) and then milled to remove their mineral fraction or subjected to proteolytic hydrolysis prior to thermal treatment to extract the protein content of mollusc shells [33].

Another topic that has to be considered when talking about fisheries byproducts is their intrinsic advantages compared to meat-industry-derived ones. First, fish-derived collagen and its peptides have a more varied composition and higher stability than its mammalian counterpart. Secondly, there is a lack of zoonotic diseases such as transmissible spongiform encephalopathy and foot and mouth disease that can affect bovine and porcine collagen. Thirdly, fish byproducts can be used to produce halal cosmetics, thus allowing their application in the Muslim community [15,34,35].

When considering meat byproducts, the main sources considered are poultry and red meat residues [6]. It is estimated that by 2029 beef production will reach 76,005 kt of carcass weight with approximately 54 to 56% of this weight being considered as nonmeat and, thus, a residue [36]. From bovine origin, the main byproducts recovered are bones, tendons, skin, blood, and internal organs, and the main products produced are collagen hydrolysates, keratin, and fatty acids [36,37]. When talking about poultry byproducts, the main residues produced are hair, feathers, internal organs, and processing wastes [37]. Another source of byproducts is the ovine industry, where up to 70% of slaughtered carcasses are byproducts, such as cartilage, carcass, meat trimmings, and bone scraps [38]. The main applications and products produced with these byproducts can be found in Table 2.

Table 2. Land animal byproducts' main cosmetic-related applications.

Source	Byproduct Example	Compounds Extracted	Application	Types of Products	References
Bovine	Pig aorta.	Collagen and keratin.	Skin elasticity and moisturizing.	Face creams, body lotions, shampoos, sunscreens, and oral supplement.	[39]
	Kidneys and liver.	Fatty acids.	Moisturizing.	Face and body creams.	[36]
	Skin, tendons, and cartilage.	Gelatine.	Structural component.	Lipstick, nail polish, and eye shadow.	[40]
Poultry	Feet and trachea.	Collagen and gelatin.	Wound healing and moisture.	Facial masks.	[41–43]
	Skin.	Melanin.	UV protection.		[41]

Table 2. Cont.

Source	Byproduct Example	Compounds Extracted	Application	Types of Products	References
Ovine	Fleece.	Lanolin.	Emollient, emulsifying, skin/hair conditioner.	Skin and hair care products.	[44]
	Cartilages and trimmings.	Collagen and peptides hydrolysates.	Antimicrobial and moisture.	Antiacne.	[38,45]

When regarding the procurement of compounds from the byproducts referenced in Table 2, the most obvious answer is hydrolysis, namely, proteolytic hydrolysis, using commercially available enzymes, such as alcalase, pepsin, or trypsin, under various conditions as these vary greatly with the nature of the byproduct used [46]. Another option may be the use of fermentation processes where the meat byproducts are used as part of the substrate which will fuel the fermentation process, as described by Kuo, Chen [47], where blood and whey from bovine source were used as substrate in the production of bioactive peptides via fermentation with lactic acid bacteria. Another case is lanolin extraction from ovine byproducts, as it is attained in the wool purifying process, where, through mixture with alcohol solution and temperature (up to 60 °C), lanolin is produced [48].

2.2. Plant-Based Byproducts

When considering the application of plant byproducts in cosmetics, the possible sources are vast, with applications in almost all aspects of cosmetics. Plant-based byproducts in the agro-food industry are estimated to produce 1.3 billion tons of residues yearly, with skins, peels, seeds, leaves, and other inedible fractions being the main residues produced [49]. These byproducts have the advantage of being rich in a plethora of so-called “secondary” metabolites which are known to exert beneficial effects in human health [4]. Of these metabolites, the most known ones are phenolic compounds, and their application in cosmetics can be either as promising bioactive compounds, such as photoprotective agents that can prevent photodamage, skin melanoma, and UV-induced skin ageing, or as structural elements capable of preserving the integrity of the cosmetic formulation through their antimicrobial or antioxidant potential [50]. Another family of compounds attained from plant byproducts with potential for cosmetic application are carotenoids. These pigments can also be used for UV protection due to their antioxidant activity, thus preventing photodamage [51]. Polysaccharides can also be attained from plant residues, and their application in cosmetics can be divided into two categories, structural and bioactive. In the first, polysaccharides application is centered upon the moisture absorption capacities, which allows their application in formulations as a moisturizing agent [52]. In the second, polysaccharides are used as bioactive agents within the formulation, capable of skin immunomodulation, wound healing, and even skin whiteners due to their antioxidant activity [51]. Plant-based lipids are also among the compounds attained from plant byproducts with potential cosmetic applications. These compounds are mainly used as barrier repair agents due to their potential to immerse themselves in the lipidic component of the skin stratum corneum, but they can also be used as moisturizers, anti-inflammatory, and wound healing compounds [53,54]. The main applications for compounds attained from plant byproducts can be seen in Table 3.

Table 3. Main compounds attained from plant byproducts and their potential cosmetic applications.

Compound	Potential Cosmetic Use	References
Phenolic compounds	Photoprotective agent, anti-skin aging, preservative agent.	[50]
Carotenoids	Photoprotective agent.	[51]
Polysaccharides	Moisturizer agents, anti-inflammatory, skin whitening, and wound healing.	[52]
Lipids	Barrier repair, moisturizer, anti-inflammatory, antioxidant, and wound healing activity.	[53–55]

One source of the aforementioned compounds are wine and grape byproducts. From this source, pomace, stalks, skin, and seeds are the main byproducts generated, with an estimated 14.5 million tons per year produced in the EU [56]. The main characteristics associated with these byproducts are increased cell viability, UV protection, antioxidant, and antimicrobial activities, with their application in cosmetics being centered upon sunscreens, antiaging, and skin depigmentation formulations and oral care products [57]. Another example is the litchi fruit, a subtropical fruit found in the Asia, of which production may reach 2.6 to 2.8 million tons worldwide, with its byproducts (peel, pericarp, and leaves) reaching up to 30% of its dry weight [58]. The main biological activities attributed to this family of byproducts are pigmentation modulation, antioxidant, and anti-inflammatory activities, which have led to applications in sunscreens, skin whitening products, skin lotion, and shampoos [59]. Another example is mango, of which production reaches 38.9 million tons/year and its byproducts, skins and seeds, account for between 35 and 60% of its dry weight, with cosmetic-related applications being centered upon antiaging [60]. The main applications and products produced with these and other plant byproducts can be found in Table 4.

Table 4. Examples of plant byproducts and their main cosmetic-related applications.

Source	Byproduct Example	Compounds Extracted	Application	Types of Products	References
Wine/grape	Leaf and stem.	Phenolic extract.	Increased cell viability, photoprotection, antioxidant, and anti-inflammatory.	Toothpastes, sunscreens, and antiacne.	[61,62]
	Grape pomace.	Oil.	Antioxidant and antimicrobial.	Antiaging and antiacne.	[56,63]
Lichi	Pericarp and skin.	Phenolic extracts.	Pigmentation modulation, antioxidant, photoprotection.	Sunscreen, antiaging, skin whitening.	[64,65]
	Pericarp.	Polysaccharide extract.	Antioxidant.	Sunscreen.	[66]
Mango	Peel.	Phenolic extract.	Skin enzymes inhibition.	Antiaging.	[67]
Citrus	Peel.	Phenolic extract.	Antimelanogenic.	Skin whitening.	[68,69]
	Peel.	Essential oils.	Anti-inflammatory and antimicrobial.	Antiaging and skin care.	[4,70]
Coffee	Silverskin, pulp, and leaves.	Phenolic extract.	Antioxidant, melanin synthesis modulation.	Skin whitening, sunscreen, antiaging.	[71,72]
Kiwi	Peels.	Phenolic extract.	Antioxidant and antimicrobial.	Moisturizing cream.	[73]

For the byproducts referenced in Table 4, various extraction procedures could be employed to extract the target compounds. For example, for phenolics extraction, one example can be found in the work of Salem, Rajha [62], where an alternative extraction procedure involving glycerine and water and mild extraction conditions (40 °C 2 h) was used to attain phenolic compounds from grape seeds. Another example can be found in the work of Yang, Wang [66], where, to attain polysaccharides from litchi pericarp tissues, they used a water-based extraction procedure, followed by filtration and overnight precipitation of the target polysaccharides with ethanol at 4 °C.

3. Benefits of Byproducts Usage

Nowadays, the use of byproducts in industry and products is the foundation of ongoing scientific and societal discussion, with the perceived effect and benefits being widely discussed in both political and academic fields. Presently, byproducts have established a

reputation as being viable sources of bioactive compounds, offering potential solutions for sustainability in various industries. Furthermore, they present an easy and natural way to grant cosmetics with functional and bioactive properties. This includes through the exploitation of compounds with high antioxidant capacity that may be used to extend cosmetics shelf life, the addition of compounds with antimicrobial activity that will be used as formulations preservative instead of chemical ones, or even as biological active compounds capable of exerting beneficial effects upon human skin, such as anti-inflammatory, hydration enhancement, pigmentation modulation, or enhanced skin elasticity and firmness [4]. Examples of this can be found in the work of Marra, Manousakis [74], where avocado leaf essential oil is described as being an active ingredient capable of extending cosmetics shelf life due to its antibacterial and antioxidant activity, or in the work of Ferreira and Santos [63], where grape pomace and grapeseed phenolic extracts were used as substitutes of synthetic antioxidants in face cream formulations.

However, their transposition from lab bench to industry production still lags behind, as stakeholders assess the perceived economic benefits of their industrial incorporation, and industrial agents and political agents evaluate the real environmental impacts of this approach.

3.1. Environmental Impact

Looking at sustainability just from an environmental perspective is also somewhat reducing in approach. Considering pillars like the economy and the environment is a must. Presently, agro-food byproducts disposal is identified as being responsible for the production of 3.3 billion tons of CO₂ equivalents annually, with their reuse being signaled as the third most important possible solution in reducing industrial impacts and climate change. This potential is reflected in the communication published by the European Commission (EC) in 2012, a Bioeconomy for Europe. In it, it is stated that to deal with the current challenges (among which stands the rapid resource depletion), Europe's production must shift to better utilize biological resources, which will deal simultaneously with a reduction in generated waste as well as a more efficient use of resources [75]. Furthermore, through byproducts' reuse and redirection, the carbon footprint of all industries involved (either the cosmetics or the byproducts producers) will be significantly reduced, a shift that will help the cosmetics industry align with the UN's 2030 Agenda for Sustainable Development, particularly with goals 8 and 12, which deal with industrial sustainable economic growth, production, and consumption [76]. Another relevant environmental impact will be the significant environmental contamination prevention, as byproducts, when treated as wastes, can release toxic substances which can lead to soil, surface, and groundwater contamination, with a particular example of seafood waste being a source of water contamination, and their disposal normally involving landfilling or incineration, solutions which are less than sustainable [77–79]. Under this light, the cosmetic industry has strived to shift its raw materials (particularly those petrol-based) towards renewable biobased ones, with industrial byproducts posing as a particularly interesting alternative.

3.2. Economic Advantages

From an economical perspective, byproducts' usage and the application of a circular economy concept may be of great advantage for both waste producers and transforming industries. From a primary producer perspective, waste treatment traditionally incurs high costs due to the need for specialized treatment and environmentally safe disposal. These processes have been estimated to cost up to USD 1 trillion yearly, to which social and environmental costs of USD 900 and USD 700 billion can be added [80]. On the other hand, adopting a circular bioeconomy (defined by the European Commission as "the production of renewable biological resources and the conversion of these resources and waste streams into added-value products" [81]) approach to byproducts' management has been estimated to be able to produce EUR 1.8 trillion of benefits to manufacturing companies and to create up to 3 million new jobs in the EU by 2030 [80].

4. Challenges and Considerations

Despite the numerous advantages related to byproducts and their applications in cosmetics, several challenges and hurdles continue to limit their widespread incorporation, use, and application. One of the primary challenges associated with byproducts used is the intrinsic logistic problems associated with their storage and transport. Two factors are critical to their quality and suitability for cosmetics-related applications, as improper handling can negatively impact byproducts' quality and activity [82]. Secondly, various byproducts are subject to seasonality, as the availability of the raw materials from which byproducts are attained may limit their application and disrupt the large-volume supply chain necessary for cosmetics production. In reality, this factor may hamper an effective application of byproducts in cosmetics products [82].

4.1. Regulatory Hurdles

Regarding byproducts and their regulatory hurdles, they may vary between countries; thus, an extra hurdle exists for companies to introduce products in the cosmetics market. One key example of such hurdles are the different regulatory authorities that govern product access to the market, as in the USA we have the Food and Drug Administration (FDA), in Europe the European Food Safety Authority (EFSA), in China the National Medical Products Administration, and in Japan several bureaus under the Ministry of Health, Labour and Welfare [83].

In Europe, the main cosmetics products regulatory regulation is the 1223/2009 directive, and in it are the guidelines for a product to be placed in the EU single market [83]. In it is the definition of cosmetics in the European market and the list of ingredients allowed, prohibited, and how they can be used [84]. In addition, in Europe, the use of byproducts is regulated by the European regulation 1069/2009, which defines what is an animal byproduct, classifies them based on potential risks, and specifies the conditions under which they can be used in various applications, including cosmetics [36,85]. In Europe, for a byproduct to be used in cosmetics it must be categorized as category 3 (the lowest risk, which includes materials which are fit for human consumption) or Category 2, specifically (i) components from animals that died on-farm and (ii) manure or digestive tract content. Category 1 is considered the highest risk and is prohibited for reuse. Products that comply with regulation 1069/2009 have to then either possess constituents that are already permitted under regulation 1223/2009 or a new compound submission must be performed.

In the USA, the system is more simplified, with cosmetics compound products needing to be in line with the Federal Food, Drug and Cosmetic Act (FDA) and the Fair packaging and Labelling Act of the Fair Trade Commission [83]. In Japan, the cosmetics regulation is very similar to the one implemented in the USA, with the additional regulation that product categories are specified, such as hair dyes, skin bleaching, or antiloss agents, and that evidence for efficacy and safety have to be provided, and byproduct inclusion in cosmetics also follows these guidelines [86].

4.2. Quality and Consistency

Traditionally, the quality of cosmetics hinges upon the careful selection of the raw materials and the techniques employed for their transformation. With byproducts, this is even more relevant as there are inherent limitations due to byproducts' nature, with compound stability, limited solubility, and skin permeability or potential for skin irritation being the main ones identified [12,87,88]. Another question is their consistency due to the inherent variability of the raw materials used. In this topic, seasonal changes and environmental factors will influence byproducts' composition, affecting their consistency and yearly availability, which can lead to alterations in cosmetics formulations and efficacy [89]. Furthermore, when talking about byproducts' quality and consistency, their collection and transportation will be crucial to ensure their quality, thus avoiding byproducts' spoilage [90].

The cosmetic industry has taken these limitations under consideration, and presently, most manufacturers are using a conjunction of various simple solutions: the first is the blending of compounds extracted from byproducts with traditional ingredients, thus reducing the amount needed in each formulation and allowing their usage throughout the year; the second is the transformation of the extracted compounds from liquids to powders, thus allowing greater production batches and greater shelf life; thirdly, selecting byproducts which are produced yearly or various byproducts that, despite being seasonable, have the targeted compounds in their composition, thus ensuring yearly availability of selected compounds and stabilizing the incorporation of byproducts into formulation and achieving consumer ready cosmetics.

4.3. Consumer Acceptance

When talking about consumer acceptance of byproducts in their products, several factors have to be taken into account: awareness, recognition, cognitive, and affective responses [91]. These factors will influence if the presence of a byproduct in a cosmetic product will influence the product's commercial performance. When discussing awareness, we are referring to the consumers' knowledge that byproducts exist and that they can be applied in products. This notion is presently well established in industrialized countries, while in developing countries this is more mixed, with younger generations being aware of these concepts and their possible applications [92].

Presently, with consumers presenting a drive for more natural cosmetics, the incorporation of natural compounds, even if they are attained from byproducts, is well accepted and viewed [93]. However, among consumers, there is also a perspective that these kind of cosmetics are more expensive and sometimes their activity is slower or that the incorporation of byproducts may limit sensorial characteristics of the cosmetic formulations, giving them unpleasant textures or smells [94,95].

4.4. Sustainability

The current sustainability definition comes from the "Our common future" report of 1987, and its core concept is that "development must be able to meet the current needs of the population without compromising future generations to meet their own needs" [96]. When considering byproducts and their incorporation into cosmetics or their transformation into new cosmetic ingredients, several different perspectives can be perceived. At a first glance, the use of byproducts towards any added-value solution other than regarding it as waste would be better from a resource management perspective. However, if factoring in the processing needed and logistics, it might be more sustainable to just do nothing at all. Weighing byproducts cosmetics against the environmental burden posed by traditional cosmetic ingredients is an interesting possibility with life cycle analysis (LCA) being a crucial tool in understanding the sustainability impact of byproduct-based cosmetics. By definition, the LCA evaluates the environmental impact of products and covers all of their life cycle from raw material extraction to raw material, and in the case of byproducts-based products, their advantage under this metric is baked in, as no raw material extraction is required; thus, the LCA will show a high degree of resource saving when compared with traditional cosmetics [97,98]. In fact, from a practical perspective, the LCA analysis of byproducts-based green cosmetics can be divided into seven steps: (i) Design: This step can have a significant impact on the products' environmental impact, and life cycle thinking (which will consider the overall impact of a product) will create a path to increase the product's sustainability during its production [99]. (ii) Sourcing: Traditionally, this step refers to raw materials' extraction and delivery. Within a bioeconomy scenario, byproducts' use will directly affect this parameter, as their usage will allow for a significant diminution of raw materials' extraction or synthesis and create a new stream of upcycling with reduced environmental impact [100]. (iii) Manufacturing: Within this step, the critical factors considered are normally the manufacturing waste, energy consumption, and greenhouse gas emissions. This is presently being circumvented by the implementation of renewable

energy sources and optimizing production procedures [101]. (iv) Packaging: This step is another one where byproducts can have a great influence on a product's sustainability claims. Presently considered the leading contributor for cosmetics sustainability efforts, packaging plays a key role in preserving the cosmetics products characteristics [102]. Presently, petrochemical plastics are used due to their multiple properties but are slowly being replaced by byproducts- or natural-compounds-based solutions capable of ensuring the cosmetics characteristics [96]. (v) Distribution: This factor impacts the raw materials, packaging, and final products' distribution. Its main contribution for the LCA analysis is the CO₂ emissions associated with transporting [103]. (vi) Consumer use: This phase's impact on a cosmetics LCA depends on if the product's application or storage needs energy and if water is required for its application and cleaning [104]. (vii) Post-consumer use: Last, but not least, this phase refers to the product's discharges and their impact on the environment due to the presence of biologically active substances that may interact with humans, animals, and plants. This is measured via assessment of the risk of aquatic toxicity, bioaccumulation, and biodegradation [105].

In Europe, the adoption of the LCA analysis by manufacturing companies has been emphasized and advised by the association Cosmetics Europe as a crucial tool to evaluate the impact of their products' production on a kg per kg basis [106].

Another advantage of the usage of byproducts-attained compounds in cosmetics is that most of them can be attained by "green chemistry" approaches. These approaches can be defined as the "design of chemical products and processes to reduce and eliminate the use and generation of hazardous substances". Green extraction technologies can be found in almost all cases of byproducts extraction as these approaches have reduced energy consumption, carbon footprints, reduced or eliminated wastes, and normally use alternate solvents [107]. Examples are the use of supercritical and subcritical fluid extraction or ultrasound-assisted extraction for molluscs to produce proteins and peptides, enzymatic hydrolysis for protein, and peptides extraction from fish and animal byproducts, subcritical water extraction for phenolic compounds' production from plant byproducts, or even the application of fermentation processes to, normally, sugar-rich plant byproducts to produce emollients, surfactants, and even bioactive components, such as human-like collagen. In addition to the process-related advantages already referenced, this approach usually produces compounds that are cleaner, with higher biological potential or nutritional quality, higher affordability, and the process itself may present higher yields, thus making it more affordable [96,108–111].

From an environmental perspective, the sustainability drive in cosmetics will also carry advantages. It will lessen pressure upon ecosystems as industry needs will be reduced, ensure a proper management of natural resources, and ensure that they are not explored beyond their capacity [82].

5. Successful Cases

When considering successful cases of byproducts' incorporation into cosmetics, one key indicator that can be considered are patents; these will be the most reliable source of information on any given product composition.

Using Espacenet and Google Patents (accessed on 1 September 2024) and filtering by the classification family A61Q ("specific use of cosmetics or similar toilet preparations" according to the International Patent Classification and Cooperative Patent Classification), 2815 patents have been filled on this topic since 2022. Of these, 2439 regard the application of plant byproducts in cosmetics, with L'Oréal (11.8%) and Unilever Global Ip Limited (1.7%) being the main assignees, and 376 were related to animal byproducts-based cosmetic applications, with the Korean Institute of Oriental Medicine being the primary assignee (9.3%) followed by L'Oréal (5.5%). Applications range from redness-correcting skin care formulations (US20240285509A1), composition for hair or scalp treatment (KR20230155841A), or a plant fat composition for cosmetic preparation (US2018110719A1). Examples of byproducts used are Vinasse (CN117547498A), a byproduct of biomass distillation that can be

used as a skincare toner, ginger byproducts (KR20230113481A) such as leaf and root, that can be used in deodorants, or even tobacco seed (US10639269B2) used in eye creams and makeup products.

When considering already-existing applications, several examples of byproducts' usage for cosmetics production can already be found in the marketplace. Some examples are L'Oréal Age Perfect Cream, which is produced with grape seed extract from byproducts of the wine industry, Estée Lauder Revitalizing Supreme+, which is produced with collagen-rich extracts from fish byproducts, Nicaraguan Coffee Intense Awakening Mask from the Body Shop, which contains extracts from coffee grounds, Dove Nourishing Secrets, which is produced with rice milk, a byproduct of rice milling, or Lush Fresh Face Masks which use various fruit and vegetable scraps to produce the face masks and their packaging.

6. Conclusions

Analyzing the data reviewed, the major conclusion that can be reached is that byproducts' incorporation into cosmetics products will play an essential role in advancing the sustainability of this industry and will make their presence in these products ubiquitous. Additionally, it is evident that byproducts' incorporation into cosmetics is already a viable and effective solution that addresses consumers' rising environmental concerns and demands for greener solutions. From an industrial perspective, byproducts' incorporation into cosmetics is already minimizing this industry's environment footprint, waste production, and energy requirements. From an economic perspective, byproducts in cosmetics will grant products a green image and make them a clear and natural choice for consumers, increasing companies' profitability in the long run.

Author Contributions: Conceptualization, E.M.C. and S.S.; validation, S.S. and M.M.; writing—original draft preparation, E.M.C.; writing—review and editing, E.M.C., S.S. and M.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Fundação para a Ciência e a Tecnologia through the grant number UIDB/50016/2020. Additionally, author E.M.C. would like to acknowledge Fundação para a Ciência e Tecnologia for his funding under the Scientific Employment Stimulus—Individual Call, number 2022.07206.CEECIND (<https://doi.org/10.54499/2022.07206.CEECIND/CP1745/CT0003>).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Conflicts of Interest: The authors declare no conflicts of interest.

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