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Review

Use of Waste from the Food Industry and Applications of the Fermentation Process to Create Sustainable Cosmetic Products: A Review

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Abstract: In recent years, the sustainability of cosmetic products has received growing interest from the cosmetic industry and consumers due to the recommendation of the implementation of the circular economy and the European Green Deal. The sustainable development strategy takes into account the reduction of waste and energy consumption, and covers all processes of producing and using cosmetics, starting from the method of obtaining raw materials, through to the process of producing cosmetics bulk, to the selection of packaging. Particularly, the selection of raw materials has a large impact on sustainability of cosmetic emulsion. One way of resource recovery is the use of agro-food by-products and discarded waste to produce cosmetic raw materials, because most of them possess value-added bioactive compounds, such as enzymes and nutrients with high functionality. Their recovery may be performed by more sustainable extraction processes, leading to natural oils, extracts, polymers, phytosterols, vitamins, minerals, and unsaturated fatty acids. A relatively new and innovative form of designing sustainable and bioavailable cosmetic raw materials is fermentation, where bioferments are obtained from plant-based and food waste raw materials. In addition, optimization of the emulsification process by applying low-energy methods is a crucial step in obtaining sustainable cosmetics. This allows not only a reduction in the carbon footprint, but also the preservation of the valuable properties of the used raw materials. The following paper discusses methods of creating sustainable cosmetic emulsions with energy-saving procedures and by using raw materials from food waste and the fermentation process.

Keywords: cosmetic industry; sustainable raw materials; resource recovery; food waste; fermentation; circular economy; carbon footprint

Citation: Krzyżostan, M.; Wawrzyńczak, A.; Nowak, I. Use of Waste from the Food Industry and Applications of the Fermentation Process to Create Sustainable Cosmetic Products: A Review. *Sustainability* **2024**, *16*, 2757. https://doi.org/10.3390/su16072757

Academic Editors: Ibukun Oluwoye, Xihong Zhang and Anita Parbhakar-Fox

Received: 1 February 2024
Revised: 18 March 2024
Accepted: 21 March 2024
Published: 27 March 2024

1. Introduction

The term of sustainability has many interpretations, but the widely accepted definition comes from the report created in 1987, entitled 'Our Common Future'. According to this definition, sustainability arises from the concept of sustainable development, which is defined as the development that can meet the current needs of the population without compromising the needs of future generations [1]. Sustainability has three pillars/dimensions: environmental, social, and economic [1,2]. Living within our environmental limits is one of the central principles of sustainable development and requires that natural capital remain intact. It assumes that the source and sink function of the environment should not be degraded [2]. The social area includes all kinds of activities for local communities, charity activities, ethical labour, as well as equal and dignified treatment of employees regardless of country of origin. This area takes into account the individual needs, such as access to employment and safe working conditions, health and wellness benefits, nutrition, education, training, and cultural expression. There is also the idea of fair trade aimed at supporting the development of small local producers, especially from African, Asian and Latin American countries. Economic development involves, for example, the creation of new jobs at the local level and business partnership. Cooperation with customers, employees, producers and suppliers play an important role in economic dimension. Economically sustainable practices lead to long-term benefits and economic development [1,2].

Sustainability has now become the priority for many businesses. The cosmetic industry is a growing economic sector, that will reach a global market value of 378 billion dollars in 2022 [3]. Due to its highly innovative, science-driven, and dynamic development, the cosmetic industry generates high levels of consumption in natural resources, such as water and energy, and is often criticized for its selection and use of raw materials, environmental impact and safety issues of final products [2,4]. However, the consumers are more and more aware of health and environmental threats and they demand products that do not harm their skin and planet [5]. Due to this fact, cosmetic sector requires a long-term vision and developing agenda of activities in order to manage sustainability issues. Nowadays the development of the company depends strongly on good practice of sustainability. For environmental performance, the crucial aspect is how companies process raw materials and plan technological procedures and logistics, and how they cooperate with customers, employees, producers, suppliers, or competitors. In the cosmetics industry, the idea of sustainable development focuses mainly on environmentally friendly activities and reducing the carbon footprint, slightly neglecting the economic and social dimensions. It covers the use of sustainable raw materials and renewable energy sources, the consumption of less water and energy in production processes, the planning of logistics in such a way as to reduce gas emissions, and the protection of ecosystems and biodiversity [1–6].

Each company should have evidence of the integration of sustainable initiatives in its business, products, and processes. The basis for systemic and integrated sustainability implementation is to provide a proper method of evaluating and reporting. It is necessary to facilitate decision making and to evaluate by cosmetic professionals the impact of existing strategies, products, and technologies. There are three ways to assess and report sustainability actions performed by companies: Corporate Social Responsibility (CSR), Design for Sustainability (DfS), and depth analysis of the Cosmetic Product Life Cycle [4,6,7]. Those methods have been developed by independent research teams and are helpful in the case of the cosmetics industry, when sustainability regulation and guidelines are not harmonized [7]. The principles of CSR and DfS consider environmental, economic, and social aspects of sustainability. The idea of CSR is that companies are responsible for societies in which they operate, and beyond making profits they must behave ethically and follow the law. There are five dimensions of CSR, namely environmental, economic, social, stakeholder, and voluntary [4]. The environmental dimension is related to the environmental management which leads to cleaner environment, while the economic dimension focuses on economic development preserving profitability at the local level. The social dimension pays attention to a social concern in business operations, whereas the stakeholder dimension involves interaction with employees, suppliers, customers, and communities. On the other hand, voluntary dimension is based on the ethical values which are beyond regulatory requirements [4,7,8]. The idea of DfS is a holistic approach which integrates and evaluates the sustainability at different stages of the product development, such as process incorporation, the life cycle perspective, and the assessment of long-term global impact based on the environmental, social, and economic dimensions. DfS considers also fundamental questions about efficiency of production and consumption by improving the usage efficiency of the product [7]. The Cosmetic Product Life Cycle model was proposed by Bom et al. and considers the life cycle phases with a sustainable approach, namely design and Life Cycle Thinking (LCT), sourcing, manufacturing, packaging, distribution, consumer use, and post-consumer use [4,7]. Taking into account these classifications, an analysis of the single life cycle stage of the cosmetic product should be carried out. This strategy is widely adopted in the cosmetics industry, and allows us to develop a cosmetic product with an improved environmental profile. Companies use different approaches to assess the impact of a cosmetic product on the environment, such as assessment of the product life cycle and its carbon and water-footprint [4,8]. Bom et al. created a spreadsheet for companies to help them evaluate their environmental performance for any cosmetic product [9].

It is well-recognized that the cosmetics industry needs functional and sustainable ingredients from renewable sources [7,10]. Consumers are looking for products made of renewable and bio-based ingredients which are commonly considered to be non-toxic and biodegradable. Meanwhile, the food industry produces a large amount of food waste, which ends up in landfills, participating in the global emission of carbon and anthropogenic methane and contributing to the development of global warming [5,11]. However, this waste has a large potential to be used in the cosmetic industry as a raw material rich in antioxidants, polyphenols, proteins, minerals, vitamins, carotenoids, lignans, polysaccharides, natural-derived polymers, and other substances (Figure 1). Eliminating waste from the food industry and turning it into valuable products became a necessity to save natural resources and avoid methane and carbon dioxide emissions, thus helping to boost a circular economy [12].

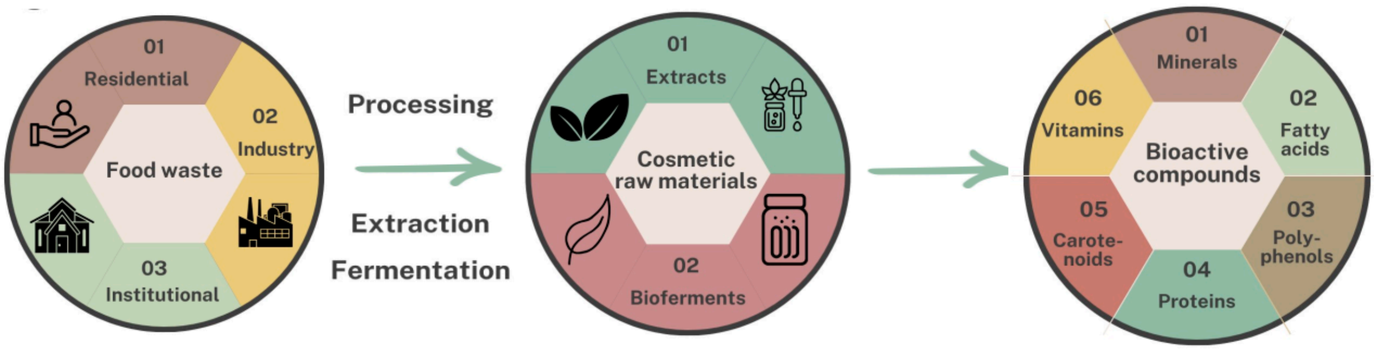

Figure 1. Schematic representation of the possible cycle of using food waste in obtaining cosmetic raw materials.

In this paper special attention has been paid to the following aspects of sustainability in the cosmetic industry: (I) using of bio-based raw materials obtained from fermentation or the waste from food industry, and (II) processing by low-energy methods. Therefore, the possibilities of using waste from the food industry and biotechnological methods of fermentation, which are compatible with Green Chemistry guidelines, for the production of cosmetic raw materials have been studied on the basis of the literature review. Methods suitable to diminish the environmental impact of the cosmetic industry by reduction in the energy consumption levels have also been considered, especially in the context of using upcycled raw-materials.

Our study not only presents the potential of using raw materials derived from upcycling food waste, but also indicates the possibility of obtaining specific groups of chemicals with already proven skin-care potential from food-waste of plant and animal origin. In addition, unlike many review papers on the food waste processing published up to date, our work does not focus exclusively on ingredients obtained by extraction process, but also takes into account biotechnological methods of processing food waste leading to bioferments, which popularity in the cosmetics industry has been steadily increasing for several years (Figure 2).

The following comprehensive literature review can be beneficial for cosmetic industry specialist who want to focus on more sustainable products to remain competitive for customers who value nature-based solutions and materials. Moreover, a tabular listing of cosmetic properties of bioactive compounds from by-products and wastes in fruit, vegetable processing, as well as fermented raw materials from plants, dairy, and the marine industry, will make it easier to reach the relevant source material.

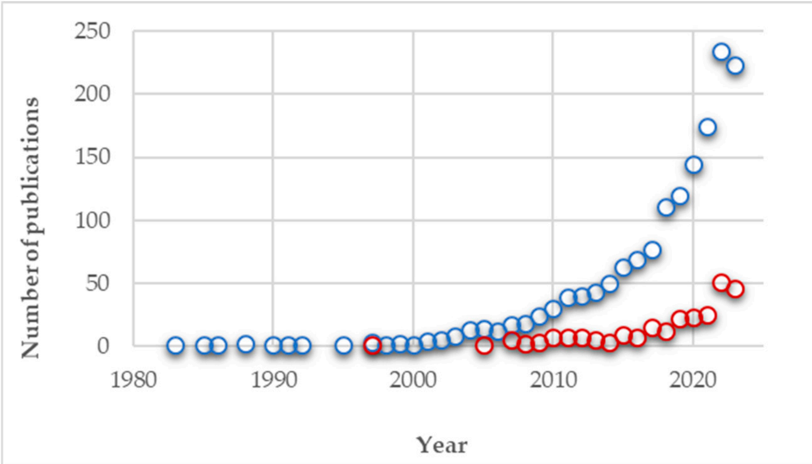

Figure 2. Scopus search results from the title, abstract or keywords with "cosmetic" AND "fermentation" (blue) compared with "cosmetic" AND "fermentation" AND "waste" (red).

2. Methods

Bibliographic positions related to the topic of the following review paper were obtained from Scopus and Google Scholar databases. The retrieval period was limited to years 2020–2024 and language to English. The search strategy included the following phrases and Boolean strings: "cosmetics" OR "cosmetic products" AND "food waste" OR "food loss" AND "sustainability" NOT "packaging" NOT "food application"; "cosmetics" AND "food waste" AND "fermentation" AND "bioactive"; "cosmetics" AND "green deal" AND "circular economy" AND "raw materials".

After preliminary search, the obtained literature positions were screened manually on the basis of their title, abstracts, and keywords. Articles should include information on the possibility of obtaining chemicals by the valorisation of waste and by-products from the agro and food industry and examples of their use in cosmetic products. Issues concerning the use of the fermentation process of food-waste-derived materials in order to obtain raw materials with skin care effects should also be included. Both papers involving in vitro and application tests for sustainable raw materials and cosmetic formulations were considered. Moreover, the literature search also included issues related to circular economy and the European Green Deal, which emerged in the context of sustainable cosmetic life cycle model and converting food and agricultural waste into high-value chemicals with potential for use in cosmetic products. In addition, the collected literature data was also expanded with references in citing papers. Rejected, in turn, were publications in which the products of agro and food waste processing were used to obtain packaging and other resources for the food industry. Finally, 169 related articles were selected as a basis for our review paper.

3. Results and Discussion

3.1. European Green Deal

The European Green Deal is a compendium announced by the European Commission in December 2019, which assumes that the economy of the European Union will become zero-emission by the year 2050 and the economic growth will be decoupled from the consumed resources [13]. The aim of this strategy is to eliminate or reduce the negative impact of human activity on the environment in the long-term perspective, making it climate-neutral, and indicating directions of economic development without increasing the consumption of natural resources [14–17]. To achieve this goals, the Green Deal involves assurance of resource efficiency in a circular economy, protection and restoring of ecosystems, preserving biodiversity by limited use of pesticides, antibiotics, and excessive fertilization in agriculture. Furthermore, the Green Deal includes a sustainable diet and consumption ('From Farm to Fork'), as well as a decrease in environmental pollution by reducing greenhouse gas emissions by at least 55% (when compared to 1990) by 2030 [17].

The main pillars of the Green Deal, which apply to the cosmetics industry, are circular economy and zero pollutions [18]. In order to meet these assumptions, several changes in the cosmetic industry will be necessary. The implementation of the European Green Deal strategy will be possible with the participation of all stakeholders from different sectors and it will require their solidarity and dialogue, as well as application of innovations, new technological solutions, and digital technologies [14].

Stakeholder engagement requires building awareness of ecosystem protection, and is necessary to promote changes in corporation culture, practice sustainability principles, and satisfy economic, social, and environmental expectations. An open and respectful dialogue, a continuous commitment to joint problem solving, as well as comprehensive information sharing, are helpful in achieving this goal. Creating sustainable development in the cosmetics industry begins with the activities of raw material producers. They can successfully implement Green Deal norms by designing processes for obtaining environmentally friendly raw materials, involving for example chemicals and procedures consistent with the Green Chemistry approach by applying biotechnological processes including microorganisms, or by using simple physical processes such as pressing, grinding, and extraction [19].

Cosmetic technologists also have great opportunities to influence sustainable development. The process of creating cosmetic formula gives technologists the possibility of selecting raw materials, with a special emphasis on the method of their obtaining, their sources, and the degree of biodegradability and toxicity to aquatic organisms. Also, suppliers' engagement can promote the transition toward the sustainability by distributing raw materials from renewable resources in supply chains established in accordance with a circular economy [20]. Consumers, whose ecological and health awareness has increased significantly during recent years, also play an important role in the implementation of the Green Deal goals. When making purchasing choices, consumers should also think about future generations; hence they more often choose ecological products containing sustainable ingredients and recyclable or biologically degradable packaging instead of plastic ones. Moreover, consumers have a decisive influence on the final fate of cosmetics packaging, as it is up to them whether it is properly segregated and recycled. Consumers' behaviour can lead to significant cost savings achieved by recycling and material reuse processes [21]. Significant responsibility also lies on the shoulders of government and university units, because they play an active role in promoting culture of sustainability by practicing environmentally and socially responsible behaviours such as financing and performing student education, and studying and publishing scientific papers on the circular economy [22].

Finally, implementation of the Green Deal requires revision and reformulation of the legal framework for action related to all identified areas, as well as quite significant financial commitment. Some larger beauty companies have committed to sustainability efforts, covering areas such as reducing gas emissions, providing sustainable product sourcing, reducing plastics usage, and inspiring consumers to consume in a more sustainable manner. Activities of Cosmetics Europe member companies, such as L'Oreal, Beiersdorf, Colgate-Palmolive, The Estée Lauder Companies, Henkel, Natura & Co., P&G Beauty, and Unilever involve setting a number of ambitious goals for sustainable development. Beiersdorf's goals are reduction energy-related greenhouse gas emissions by 30% in absolute terms and to cut supply chain emissions by 10% by year 2025. Moreover, Consumer Business Segment production sites are to become climate-neutral by 2030. These goals are to be achieved by switching from fossil fuels to renewable energy sources, and researching innovative ways of capturing greenhouse gases from the atmosphere to use them in the future product development [23]. The Estée Lauder Companies, on the other hand, focus on sustainable development in product formulas using the principles of Green Chemistry. The company concentrates on training chemists on green principles and practices, developing internal processes, goals, and tasks leading to the use of green chemistry at work [24]. An interesting way to promote sustainable development is to educate consumers about the impact of cosmetic products on the environment. This strategy has been implemented by L'Oreal, which has carefully assessed the product's impact on the environment and has taken actions to reduce it. The company has developed a Product Impact Labelling system to offer consumers information about the environmental and social impact of the cosmetic they purchase. This labelling system was introduced at first in 2020 for L'Oreal products available in France, and then in 2021 in Germany for Garnier hair-care products [25].

Industry needs harmonised requirements, which will be applicable across the board, and their proper enforcement. The European Parliament and the Council are working on regulations which will establish a framework for setting eco-design requirements for sustainable products and repealing Directive 2009/125/EC. The primary objective of this document is to introduce principles that will lead to more sustainable products. On 30 March 2022, the European Commission adopted a proposal for a Regulation of the European Parliament and the Council, number 16723/23, which establishes a framework for setting eco-design requirements for sustainable products [26]. The regulation is a set of general requirements covering almost all product categories, and most likely it will become effective in the second quarter of 2024. On the other hand, detailed sectoral law will be introduced through separate legal acts. The priority products for which sectoral acts will be developed at first are detergents and chemicals. The regulation is intended to be in line with the assumptions of green transformation and extend the life cycles of products in accordance with the principles of the circular economy [14,17].

Nevertheless, according to the literature review by Pérez-Rivero et al. there are already examples of collaboration between the food industry and cosmetic manufactures which promote the circular economy and reducing agri-food waste [27]. NoPalm Ingredients in the Netherlands valorises agricultural wastes and other by-product streams as a nutrient source for oil-producing yeast. Recently, this company has signed a collaboration agreement with Colgate-Palmolive under which it will intensify their pilot studies and scaling-up efforts. On the other hand, Clean Food Group has lately signed an agreement with Doehler group to accelerate commercialization of their process based on fermentation of ready-to-waste food stocks with a non-GM yeast to produce palm oil substitutes for food and cosmetics applications. Similarly, Genomatica and Unilever plan to join their forces to scale plant-based alternatives based on biotechnology in order to obtain value-added chemicals with potential application in the beauty and personal care products [27]. Furthermore, the Korean company LABIO ferments vegetable oils with *Pseudozymas* spp. In order to obtain emollients with enhanced properties, namely with beneficial influence on the cheek resident skin microbiota. The results show improved microbiome composition and enhanced alpha-diversity, which is the factor determining a healthier microbial ecosystem [28].

3.2. Sustainable Cosmetic Products

Sustainable cosmetic products are a response to the introduction of the European Green Deal. While sustainable development is a commonly known term in the literature, the concept of sustainable cosmetics has no definition and legal regulations.

The legal gap is currently filled by the ISO 16128 standard [29,30] which provides some guidelines on definition and criteria for natural and organic cosmetic ingredients and products [31]. It is divided into two parts: Part 1 covers definitions for ingredients (published February 2016), whereas Part 2 defines rules for calculation of the natural and organic content in ingredients and products (published August 2017). The list of processes and solvents included in the ISO standard is only informative; there is no restrictive approach in this matter. Similarly, the process of certification and certification body have not been specified. Unfortunately, ISO 16128 is not applicable when it comes to product communication, such as claims and labelling, human and environmental safety, and socio-economic considerations, e.g., fair trade, characteristic of packaging materials, and regulatory requirements applicable for cosmetics. Another option to confirm the naturalness of a cosmetic is certification by well-known certification bodies like Ecocert, Ecocert Greenlife, Cosmebio, BDIH, ICEA, and the Soil Association, which verify products according to the uniform COSMOS (Cosmetic Organic Standard) standards [32]. The differences between ISO 16128 and COSMOS standards are presented in Table 1.

Table 1. The differences between ISO 16128 and COSMOS standards.

ISO 16128 Standard	COSMOS Standard
The guide does not contain precise requirements and criteria.	The guide contain precise requirements and criteria.
Risk of different interpretations of the guidelines.	A clear interpretation of the standard.
It only applies to raw materials and cosmetic formulas.	A comprehensive approach to: raw materials, recipes, packaging, marketing claims, production and storage of cosmetics, as well as environmental aspects.
Lack of external control.	Audit once a year.
There are no definitions of natural and organic cosmetics, there are only definitions of natural and organic raw materials.	A clear definition of naturality for both finished products and raw materials.
It contains only recommendations regarding the use of natural solvents and the principles of Green Chemistry.	It contains requirements regarding the use of natural solvents and the principles of Green Chemistry.
It does not regulate the issue of preservatives permitted in natural cosmetics, allowing the use of all preservatives in accordance with the legislation, including: parabens and phenoxyethanol.	It precisely defines the preservatives allowed in natural and organic cosmetics.
No requirements for fragrance substances, which makes possible using, for example, synthetic fragrance compositions.	Strictly defined requirements for fragrances.

Nevertheless, the Green Deal most broadly brings all the aspects of sustainable cosmetics at every stage of its creation, and thus, created sustainable cosmetics may act as stimulators of sustainable development in the cosmetics industry. According to the literature, there are no raw materials, packaging materials, or practices that can be considered 100% sustainable [9]. However, it is possible to significantly reduce the impact of the cosmetic product on the environment by integrating three major domains: social, economic, and environmental. The term 'sustainable cosmetic product' can be explained through a holistic approach applied to the entire process of the production and use of cosmetics. It should be also referred to the Cosmetic Product Life Cycle model proposed by Bom et al., which includes design and Life Cycle Thinking (LCT), sourcing, manufacturing, packaging, distribution, consumer use, and post-consumer use (Figure 3) [1,7,9].

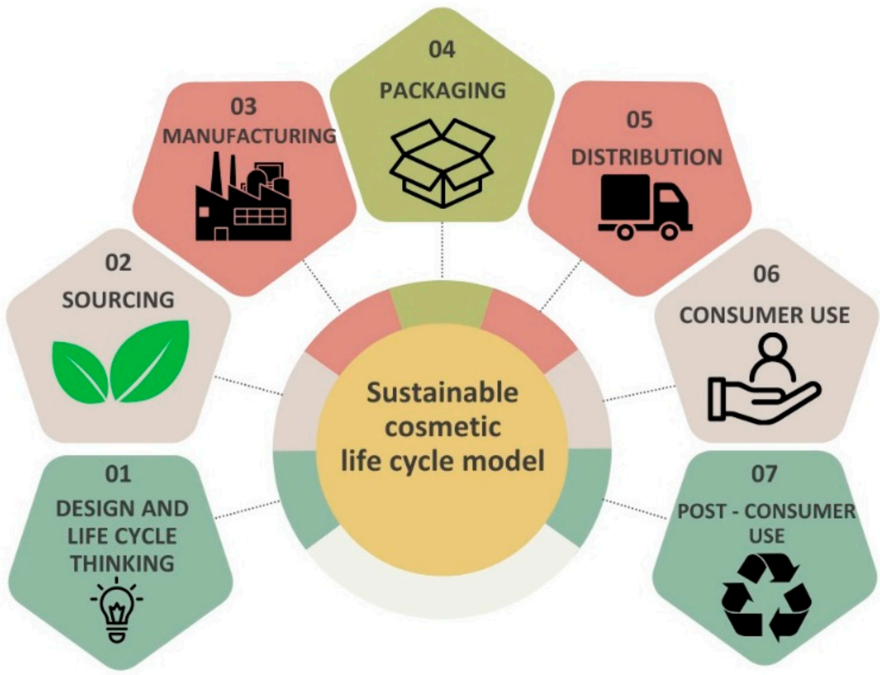

Figure 3. Sustainable cosmetic life cycle model.

3.2.1. Design and Life Cycle Thinking (LCT)

The phase of the design of cosmetics products significantly affects the environment, and decisions made at this point will affect the remaining phases of the product life cycle [4,7,9]. LCT's goal is to improve sustainability dimensions of cosmetic products in a prominent and holistic manner. It covers the planning of how to improve individual phases of the product life cycle in order to minimize the negative impact on the environment at all stages [15,16,33]. Designing sustainable cosmetics includes embarking on a proper transformation of the cosmetic business. This should lead to more mindful corporates, not only in environmental issues, such as climate change, resource and energy savings, reduction of waste and carbon footprint, and responsible production and consumption, but also in social and economic dimensions, such as fair trade and ethical sourcing [9]. Research shows that international cosmetic companies pursue initiatives to improve sustainability dimensions holistically, taking into account the entire product life cycle, while small or medium local companies focus on the use of natural, green, or organic ingredients as main part of their sustainable products. The reason for this situation is the lack of resources and a holistic understanding of the impact of the life cycle [9,33–36]. Life cycle assessment is also a valuable environmental management tool to assess waste management in the food industry [37]. One of the solutions to reuse by-products discarded by several agro-industries is their use as a source of sustainable cosmetic raw materials [38].

3.2.2. Sourcing of Raw Materials

The selection of raw materials is the most complex and important process for assessing the impact of a cosmetic on the environment. It refers to all the procedures necessary to extract raw materials, process them, and deliver them to the cosmetic manufacturer [7]. Considering the fact that raw materials are extracted or synthesized in many different parts of the world, and are delivered to the cosmetic manufacturer not only by the producer but also through several distributors, the evaluation of sustainability in this phase of the product life cycle is very complicated [7,9].

Due to the need to consider multiple parameters, the decision-making process in the selection of the cosmetic raw material and its supplier may be extremely complex. Developing and implementing appropriate hybrid multi-criteria decision-making (MCDM) approach could be helpful in this matter, what has been already proven in other branches of industry [39].

There are several key aspects that should be considered when selecting sustainable raw materials. First is the origin of the raw material, which can be synthetic as well as of plant or animal origin, but also may come from upcycling and renewable source. In the case of obtaining plant-based raw materials, e.g., for extracts production, the way in which the plant was cultivated and propagated (agriculture/wild origin) should also be taken into account. Plant growth should take place in the laboratory conditions, preferably in bioreactors, which will help preserve biodiversity and water resources. It is worth keeping in mind that the ingredients referred to as natural, naturally derived, organic, and green, which are quite often associated with sustainable cosmetic products, may result in a less preferable environmental profile of the cosmetic if assessed from a life cycle perspective [7,9]. The lack of a single definition of natural ingredient causes that several groups of producers came out with their own guidelines regarding raw materials and their extraction procedures. Therefore, each of such ingredients should be examined by a holistic view concerning ethical, social, and economic responsibility. Nevertheless, bio-based composition of the ingredients may bring positive contributions to the environment [40].

Another aspect in selecting sustainable cosmetic raw materials is deciding on the raw material processing method. Raw materials used to produce cosmetics may be obtained as a result of various physical processes and chemical reactions. Sustainable methods of obtaining raw materials are those that leave a low carbon footprint in the environment, and include biotechnological processes involving microorganisms, and physical processes such as grinding, pressing, extraction, and chemical reactions consistent with Green Chemistry guidelines. In addition, an important role in the sustainability of raw materials plays their biodegradability and toxicity to aquatic organisms [6,7,9]. Moreover, from a social point of view, fair trade of raw materials is a very important aspect [7]. In the stage of selecting raw materials, the formulator should be able to assess the impact of all choices on sustainability for any type of cosmetic product [9]. The proposed criteria for evaluating the sustainability of raw materials are presented in Table 2.

Table 2. Criteria for evaluating the sustainability of raw materials.

Criteria	Rating
Origin of the raw material	Natural (from agriculture or wild origin) Produced by microorganisms Upcycled
Method of processing the raw material	Physical processes (grinding, pressing, extraction) Chemical reaction according to the Green Chemistry approach Biotechnological processes
Biodegradability of raw material	Readily biodegradable according to OECD 301 A, B, C, D, E, F regulations: if 60% (or 70% for some tests) of the organic carbon in the material is converted to CO_2 within a 10-day window, and 100% within 28 days.
Toxicity to aquatic organisms	Non-toxic
Fair trade	The raw material comes from fair trade

3.2.3. Manufacturing

There are many aspects in the cosmetics production that can be improved in order to reduce the environmental impact. One of the main issues is the reduction in post-manufacturing wastes and the increase in their biodegradability [38]. Conventional disposal of cosmetic industry waste consists of incineration and reprocessing through coagulation/flocculation or pressure flotation, which all involve environmental, energetic, and economic costs [38]. Therefore, an introduction of innovative and sustainable technologies of waste processing is necessary. One of them is anaerobic digestion for waste-to-energy production, where pre-treatments are aimed at increasing biogas yields [38,41]. An example of a company that processes waste generated during the production of emulsifiers by means of the methanation process, and which involves the decomposition of organic matter under the influence of microorganisms in anaerobic conditions, is the Seppic company. The result of the waste methanation process is biogas used to generate energy, as well as bioferment, used as fertilizer. This is a good example of optimal use of both the production process and waste post-production for the good of the environment. Thanks to the methanation process of the waste, the company reduces greenhouse gas emissions by 100 T per year when compared to the combustion process [42].

Waste materials derived from cosmetics production are generally characterized by a high content of suspended solids, fats, oils, and detergents, which are non-readily biodegradable compounds, and require physicochemical pre-treatment, e.g., thermosonication to increase available organic matter [38,41].

Another aspect of the manufacturing process is greenhouse gas emissions and energy consumption. The latter needs to be reduced by using renewable sources of energy, such as solar (photovoltaic) or wind power plants [1,41]. Furthermore, industry accounts in total for about 20% of all water withdrawals. Water is also a key element in the cosmetic industry [43,44]. It is one of the main ingredients in the cosmetic formulations, and is present at all stages of the cosmetic product life cycle. Water is necessary in the manufacturing process for the heating and cooling of cosmetic bulk, the cleaning of equipment, as well as the production of raw and packaging materials. It leads to high consumption levels of this natural resource; therefore, a commitment to reduce the water footprint is absolutely necessary. The recommended actions to reduce water consumption in the cosmetic industry are: developing waterless or concentrated cosmetics, adopting circular water management in factories, using sustainable raw materials, optimizing manufacturing processes by reducing heating and cooling processes, changing cleaning procedures, looking for alternative water sources in cosmetic formulations by using fruit or vegetable water, and collecting and reusing wastewater. Moreover, the use of biodegradable, recyclable and reusable packaging and the introduction of changes in the distribution of products, for example, by reducing the frequency of delivery and miles of transportation, also allows for reducing water consumption [43,44]. The appropriate handling of wastewater from the cosmetic industry, namely using purification methods, such as coagulation, advanced oxidation, or biological treatment, allows reducing the toxicity of wastewater [45].

3.2.4. Packaging

Despite the existence of waste management systems, plastic packaging is the most often used option in the industry due to its flexibility and light weight [46,47]. It causes the pollution of land and marine ecosystems and has a negative influence on human health [46,48]. Due to the fact that the market for recycled plastics is still weak and the cost of treatment and waste disposal is high, the recycling of plastic packaging is still a challenge. According to the European Strategy for plastics in a circular economy introduced by the European Commission, all plastic packaging must be 100% recyclable (or reusable) and 55% should be recycled by 2030 [49]. To make packaging more sustainable, it should have an increased recycling rate, based on the effective amount of plastic waste turned into secondary plastics [46–50]. Another solution in terms of alternative packaging is the use of bio-based materials derived from bamboo, seaweed, corn starch, mushroom fibres, and avocado nuts [51]. According to a survey conducted by Bom et al., the following packaging materials have an impact on sustainability (starting with the one with the greatest impact): non-renewable materials, plastic/polymeric materials, aluminium, wood, glass, recycled materials, and biopolymers or plant-based plastics [9].

3.2.5. Distribution

Transportation of ingredients, materials, packaging, or final products and related emission of CO_2 have a large influence on the environment. Due to the fact that fuel consumption accounts for at least 30% of transport operating costs, a change in the type of transport system from road to rail and from air to sea is highly recommended [6,9]. Using of electric or hybrid vehicles, choosing the best route of travel, minimizing the frequency of deliveries, and avoiding unnecessary wheel load, such as transporting glass packaging, can significantly reduce CO_2 emissions during cosmetic distribution [6,52,53].

3.2.6. Consumer and Post-Consumer Use

The influence of consumer use varies according to the product category because it depends mainly on the depletion of water resources and the energy consumption needed to heat the water and rinse off the cosmetic product. The highest water consumption was observed when using rinse or wash-off cosmetics, such as shampoos, conditioners, shower gels, and soaps. To minimize the environmental impact of this phase of the product life cycle, 2-in-1 products that do not require extensive rinsing should be introduced on the market [7,53]. Consumer education in terms of sustainable consumption, such as dosing the correct amount of the product and using less water to rinse off the cosmetics, is necessary because, according to the researchers, approximately 90% of the CO_2 emission generated during the life cycle of the product comes from consumer use [7,9].

The post-consumer use phase concerns the handling of packaging waste after the product has been used. Customers should be aware of the proper segregation of packaging waste, because the system that supports the collection and recycling at the end of the product's useful life is an essential element of packaging sustainability [9,33]. The following strategies may also be implemented: packaging reuse (e.g., refilling) and recycling, incineration with energy recovery, or composting [9]. Another issue is the impact of rinse-off cosmetics, which are released to the aquatic environment after being used. In order to assess their toxicity to aquatic organisms, the most widely used parameters are: acute aquatic toxicity, chronic aquatic toxicity, bioaccumulation, and biodegradation [7].

3.3. Food Waste as Sustainable Raw Materials

When in 2015 the European Commission adopted the first Circular Economy Action Plan, food waste management was identified as a priority [54]. The depletion of non-renewable resources and the need for better management of post-production waste were identified as a criterion for sustainable production. Therefore, the search for green resources, such as waste from other industries and biomass, should be taken into account [37,54,55]. Cosmetic industry needs to find its way to reduce the use of virgin raw ingredient and maintain socio-economic profile [56,57]. The mainstreaming of the idea of upcycling in food systems has a large potential to improve circularity in the food system and offers new opportunities to create sustainable raw materials for the cosmetics industry [58–61]. A large number of food industry wastes is recovered as value-added products by more sustainable and innovative extraction processes, with a potential of being incorporated into cosmetic products [62]. Extracts from food waste, especially those from organic farming, are effective and bio-sustainable as they do not contain residual pesticides or potentially toxic chemicals, and therefore represent a valid alternative to regular plant-derived extracts [55].

3.3.1. Upcycling

Many imperfect vegetables and fruits are rejected from sale due to the use of aesthetics to classify and accept fresh food for sale and consumption. It is estimated that more than a third of total farm production is lost due to aesthetic standards in Europe and the UK, which corresponds to approximately 1.3 billion tonnes per year [52,53,63]. Food waste accounts for 8–10% of total anthropogenic greenhouse gas emissions, demonstrating that agriculture puts a strain on planetary ecosystems [58]. The residues from the agro and food industry include seeds, kernels, fruits and vegetables skin, shells, peelings, bran, plant leaves, fruit pulp, and residues remaining after extraction of juice, oil, starch, and sugar, which can all be rich in bioactive compounds such as vitamins, minerals, and phenolic compounds. Unfortunately, residues end up most often in landfills, significantly contributing to global pollution levels by producing significant amounts of methane, which consequently leads to greenhouse gas emissions [52,53,58,64,65].

The interest in proper waste management is increasing worldwide, as reuse of waste plays an important role to overcome environmental pollution. Many initiatives are needed to limit food waste across the value chain and in public-private partnerships [58]. The answer to food waste problems seems to be upcycling [60,66,67]. Upcycling is a method of reuse of industrial by-products with the aim of generating new raw materials with added values [52,58,64,68]. In response to the Green Deal and consumer demand for bio-based and natural cosmetic products, for several years there has been a grooving interest to utilize agricultural waste as cosmetic raw materials [69]. As a result of upcycling, orange, lemon, banana, and mango peels, as well as grapes and olive oil pomaces, sugarcane bagasse, coffee grounds, wheat straw, and seeds and kernels of fruits, stemming from specific processes such as pulping, peeling, straining, and branching, are reused and processed into cosmetic raw materials [12,64].

The recycling and reuse of agro-waste using green technologies will reduce water consumption, greenhouse gas emissions, and worldwide total pollution [70,71]. As a result of biotechnological transformations of waste from the food industry, various products such as biofuels, biomass, biofertilizers, biosorbents, and value-added components can be produced via anaerobic digestion, fermentation, and composting technologies [64,65,72]. Valorisation of wastes and by-products can contribute to minimal waste generation or fulfil the popular 'zero waste' concept. Furthermore, this approach is in accordance with current circular economy assumptions in the context of using industrial waste as the starting material to extract compounds with high value added [57,59,73]. The upcycling of food waste is a transformation that may lead to stable ecosystems and a circular economy by reducing environmental impact and climate change, as well as creating a more sustainable food system [71,74,75]. However, upcycling of waste also brings several challenges, e.g., the logistics of high amounts of waste is still a roadblock to scalability and stability of food waste ingredients, especially when they are processed out of place of their natural origin.

Too few companies dealing with waste upcycling mean that waste often has to be transported from another country, which is a very expensive approach. Waste from the food or dairy industry very often is microbiologically contaminated and requires appropriate separation of unwanted microorganisms, which is also a cost-generating process. Lack of quality protocols and standards for upcycling is another barrier which the upcycling industries have to deal with. Additionally, current standards for upcycling focus only on conventional materials and techniques, and the governments usually do not support small upcycling businesses. A potential solution that will help to address these barriers could be a financial support for upcycling businesses from the governments [76]. Also the maintenance of bioactive properties of upcycled raw materials in the cosmetics formula may be a challenge. However, this topic still requires further study [53,61,62].

3.3.2. Extraction Methods of Recovering Bioactive Compounds from Food Waste

It is extremely important to implement so-called "green procedures", which include environmentally friendly chemical processes and synthetic methodologies that reduce or eliminate the use of hazardous and toxic chemicals at each stage of sustainable cosmetic raw materials production. Therefore, only those extraction procedures will be defined as "green" when they reduce energy consumption, ensure safety and high quality of the extract, and use solvents with low environmental impact [77]. Value-added components are selectively extracted from the food matrix through biochemical, chemical, or thermal/physical methods [69,72]. The main techniques in the bioactive compounds recovery for the cosmetics industry are the extraction methods, mainly based on solvent extraction, supercritical fluid extraction, subcritical water extraction, use of enzymes, and some non-conventional techniques, like pulsed electric field ultrasound and microwave assisted extractions [68,78].

In solvent extraction, a proper amount of raw material is exposed to different organic solvents, which dissolve active ingredients and also other flavouring and colouring agents, such as anthocyanins [68,78,79]. To remove solid residues, samples are usually centrifuged and filtered. The benefits of this type of extraction methods are the low processing cost and ease of operation. Unfortunately, they have also several drawbacks, such as necessity of applying elevated temperatures and long processing time, which can cause degradation of natural bioactive components. Moreover, an evaporation process is required to concentrate the extracts [68,78,79]. A green alternative to the organic solvents is to use deep eutectic solvents (DES), obtained via mixing natural and renewable materials, such as glycerol and salts of organic acids. DES can be used effectively for the extraction of bioactive compounds, namely polyphenols from food industry by-products [65]. A kind of solvent extraction is the Soxhlet extraction, which involves repeated washing of the matrix with a fresh solvent. The advantages of this extraction type are: higher solubilization of the analyte due to the use of hot solvent and the possibility to apply it to many food matrices [68,79].

Another method of solvent extraction, which is considered as the most environmentally friendly, is supercritical fluid extraction. The solvent used in this method is supercritical carbon dioxide (SC-CO_2), which is a non-explosive, non-toxic, and inexpensive alternative to the organic solvents [78]. SC-CO_2 has ability to solubilise lipophilic substances and it can be easily removed from the final extract. There is also a wide range of compounds which can be used as cosolvents in this technique, and SC-CO_2 can be modified with ethanol or methanol in order to obtain higher extraction yields in the case of some active ingredients. The supercritical fluid extraction process involves placing the raw material in an extraction container equipped with temperature and pressure controllers. Next, the extraction container is pressurized with the fluid by a pump [68,78,79]. Finally, fluid and dissolved compounds are transported to the separators and, after that, the fluid is regenerated and recycled or released to the environment. The advantage of carbon dioxide is that it reaches the supercritical state at relatively low temperatures, just above 31 °C. This allows to obtain plant extracts without degrading them or losing their properties, which often happens at higher temperatures. Supercritical CO_2 extraction is currently the most effective method to extract nonpolar compounds such as oils [79].

The promising alternative technology for the extraction of phenolic compounds from different sources, especially plants and algae, is subcritical water extraction. Subcritical water refers to water at a temperature between 100 °C and 374 °C, and a pressure below the critical pressure of 22 MPa. This method is characterized by a shorter extraction time, lower solvent cost, higher quality of the extracts, and, most importantly, it does not generate wastes destructive to the environment [68,78].

Enzyme-assisted extraction is a method of extraction which is used to facilitate the release of bioactive compounds from plant cells present in the food waste. Enzymes such as cellulase, β-glucosidase, xylanase, β-gluconase, and pectinase help to degrade plant cell walls, which act as barriers to the release of intracellular substances, and which still contain polysaccharides such as cellulose, hemicellulose, and pectins. The solvent of this method is water, rather than often harmful organic chemicals [78].

Another method that increases extraction efficiency is ultrasound-assisted extraction (UAE). The release of bioactive compounds is facilitated due to the disruption of the cell walls caused by ultrasounds, which induce a greater diffusion of solvent into cellular materials [78,80]. The extraction technique that significantly reduces processing time is microwave-assisted extraction (MAE) that combines microwave and traditional solvent extraction [78,79,81].

Among the extraction methods used in sustainable acquiring bioactive components from plant material, pressurised liquid extraction (PLE) should also be mentioned. It is based on operating with conventional solvents under high temperature and pressure. The instant controlled pressure-drop (DIC) method which, combines short duration time, elevated temperature, and quick depressurization toward a vacuum, also allows to obtain extracts with superior quality and prevents their thermal degradation, especially in the case of polyphenols-rich mixtures. On the other hand, response surface methodology (RSM) as a statistical tool for optimization of extraction procedures can also be used. RSM is an experimental modelling which allows process optimization, for example by reducing the experimental runs. It also helps to find the most positive response for the specific extraction strategy, consequently offering the most sustainable procedure [82].

It is difficult to clearly indicate the most efficient extraction method. The choice of methodology is dictated not only by its advantages or drawbacks, but also by the physicochemical characteristics of the materials and the type of bioactive compounds to be extracted. In the case of oil compounds extraction, the most efficient method seems to be supercritical CO_2 extraction. However, in the case of polyphenolic compounds, the most effective method seems to be supercritical fluid extraction (SFE) with the use of deep eutectic solvents (DES) as emerging green solvents. Moreover, SFE has the ability to induce chemical transformations of agri-food materials, such as hemicellulose hydrolysis. Those methods are environmentally friendly and do not release toxic substances to the environment [83].

Another important aspect in the extraction process is moving from the laboratory to the industrial scale. The green extraction processes have the potential to permit feasible scaling up to industrial extraction [84]. When scaling up, several factors should be taken into account, namely: instrumentation, batch/flow process, kinetics, economics, and energy consumption. Increasing the scale of extraction can start with the use of mathematical models that are based on kinetics-based approaches and solubility-based approaches. The goal in the industrial-scale process is to obtain processing conditions and parameters which will result in similar yields and composition of extracts when compared with the laboratory-scale setup [85].

There are also several methods for qualitative and quantitative analysis of functional extracts obtained from food waste. One of them are advanced chromatographic and spectroscopic techniques, such as High-Pressure Liquid Chromatography (HPLC), Gas Chromatography coupled with Mass Spectrometry (GC-MS), or Fourier Transform Infrared (FTIR) spectroscopy, applicable to the compounds such as fatty acids methyl esters, cinnamic acid derivatives, and glycerine [65,86].

3.3.3. Cosmetic Properties of Phytochemicals Derived from Agri-Food Waste

Agro-food wastes, which most often are peels, seeds, shells, pomace, and leaves, can be considered a rich source of chemicals with significant skin-care potential, such as carotenoids, tocopherols, glucosinolates, phenolic compounds, and fatty acids. They exhibit a broad spectrum of action on the skin and can be incorporated into cosmetic products, particularly those with moisturizing, anti-aging, and antimicrobial properties. Products containing such bioactives can benefit the skin with various dysfunctions, including dryness, aging, or acne. Raw materials extracted from agri-food wastes are often richer in bioactive compounds than their counterparts extracted from fresh raw materials, e.g., the waste from the olive industry could be a greater source of polyphenols than the olive oil itself [79]. Additionally, they allow the valorisation of agri-food residues, leading to more nature-based cosmetic products. The growing drive to obtain cosmetics based on sustainable ingredients is reflected in numerous research papers on the skincare effects of bioactive compounds extracted from food waste.

The work by Pereira et al. provides a valuable overview of the possibility of using agri-food waste as a source for phytochemicals with antibacterial activity [87]. Among them, the prominent one is the research conducted on the activity of essential oil obtained from *Citrus reticulate* Blanco peel against *Cutibacterium acnes*, the bacteria responsible for the formation of skin acne. The results obtained by the researchers indicate that the antibacterial activity of this oil against C. acnes is higher even than that of synthetic antibiotics commonly used to treat acne, such as erythromycin, clindamycin, and tetracycline. This indicates the great application potential of essential oils extracted from citrus fruit peels [88].

In turn, Ferreyra et al. points to the possibility of using grapevine woody by-products, such as bunch stems and canes, as a source of bioactive phenolic compounds with well-recognized antioxidant, antimicrobial, antifungal, and anti-aging properties [89]. Particularly noteworthy in this group of compounds is trans-resveratrol, which is used in cosmetic formulations as an anti-aging and anti-hyperpigmentation ingredient which prevents skin discoloration by suppressing tyrosinase activity during melanogenesis [90–92]. Another phytochemical with strong antioxidant activity is ferulic acid, which can be also stabilized in cosmetic products in the form of lipid carriers [86] and liposomes [93]. It has been proved that ferulic acid does not exhibit toxicity even at higher concentrations. Moreover, the regeneration studies have shown a significant improvement in skin condition during application of a liposomal nanosystem containing ferulic acid. Importantly, the source of ferulic acid was brewers' spent grain, which is one of the most abundant by-products in the beer industry, causing vast environmental problems [93].

Among many potential skincare applications of compounds extracted from agri-food wastes, the research on skin photoaging treatment is worth mentioning [94]. Martínez-Inda et al. studied the phenolic composition of 18 different vegetable residues collected from household wastes and containing, among others: tomato, potato, and garlic peels; cabbage and eggplant peels and stems; avocado peel and pit; beet leaves, peels and stems; strawberry leaves; pear, orange, tangerine, and kiwi peels; and peanut shells. Extraction procedures applied by researchers led to the mixtures rich in phenolic compounds like caffeic acid, chlorogenic acid, p-coumaric acid, and protocatechuic acid with high antioxidant activity. Moreover, the authors demonstrated that phenolic compounds from food waste extracts may offer a significant photoprotective action, and established a regression model correlating the total phenolic content of the extracts with their photoprotective action (SPF) [95]. Value-added phytochemicals derived from food waste can also be used in wound healing formulations. Bassam et al. developed a gel incorporated with chitosan nanoparticles loaded with ethanolic extracts of kiwi peels or yucca seeds. The high content of antioxidants, vitamins and anti-inflammatory agents resulted in the enhancement of skin burn healing performance [96].

It Is worth noting that a significant number of compounds derived from agri-food industry waste are already patented as anti-aging, moisturizing, and sun protection agents with potential for cosmetic and dermatological application. This can be confirmed by a literature study conducted by de Mello et al., who studied patent applications for coffee and coffee by-products as active ingredients in cosmetics. They showed that of the fifty-two patents relating to coffee and coffee by-product used in cosmetics, three were for coffee silverskin processing, one for peel and pulp, one for pulp, and one for beans together with leaves [97].

The on-going interest of researchers in the fermentation is also reflected in obtaining sustainable cosmetic formulations, as biocompatibility is considered the major advantage of cosmetic ingredients derived from fermentation processes. Furthermore, the fermentation can be perceived as an innovative tool in the synthesis of new active compounds or tailor-made ingredients to solve specific skin problems [98,99].

One of the frequently used cosmetic ingredients is lactobionic acid, which acts as an anti-aging and keratinizing agent. It has been demonstrated that *Pseudomonas taetrolens* was able to produce high-purity lactobionic acid when cultivated in the fed-batch culture under co-feeding conditions using highly concentrated whey with yeast extract and peptone [100].

Similarly, exopolysaccharides (EPS) have also been proved beneficial in the skin-care products due to their biocompatibility, anti-microbial, anti-oxidative, and anti-photoaging effect [101]. Sun et al. reported highly efficient synthesis of EPS by the *Zunongwangia profunda* SM-A87 strain in whey. Their study revealed also that the obtained EPS were characterized by significant moisture-retention ability and antioxidant activity, indicating their great application potential in skincare products [102].

The combination of producing β-glucosidase *Schizophyllum commune* mycelia and the aqueous extracts of *Citrus unshiu* peel containing flavonoid glycosides were used to obtain value-added chemicals with biological activity. The photoprotective potential of fermented *C. unshiu* peel extract with *S. commune* was tested in human dermal fibroblasts exposed to UVA radiation, and it was revealed that it had an inhibitory effect on human interstitial collagenase expression. This allows to speculate that the material under study may exhibit protective potential against photoaging-induced dermal collagen loss [103].

Low-cost by-products and residues of agri-food industry origin have also proved their potential in production of different pigments and aroma compounds by the fermentation process with diverse group microorganisms. Carotenoids from grape waste fermented with *Monascus purpureus* and fruity aroma (mixture of alcohols and esters) from sugarcane bagasse and sugar beet molasses fermented with *Kluyveromyces marxianus* are only a few examples of possible application of bioferments in the cosmetic products [104–106].

Natural loss of collagen that progresses with age causes morphological, structural, and functional skin deterioration, bringing a challenge to the cosmetic industry. However, the use of cosmetic products enriched with collagen has proven to be a fine solution. In recent years, fish collagen, which shows many advantages over mammalian-based collagen, has gained the special attention of researchers. Application of fish collagen reduces zoonosis transmission risk and cultural-religious limitations, but also brings the cost-effectiveness of manufacturing process and high bioavailability. Recently, the attention of researchers has focused primarily on the use of fish wastes (i.e., skin, scales) as a cheap and environmentally friendly source of collagen [107].

For the extraction of collagen peptides, fish waste fermentation with *Lactobacillus* bacteria could be applied. Khan et al. tested biological activity, namely the cellular cytotoxicity and proliferative effect of such-obtained fish collagen by using HaCaT (Cultured Human Keratinocyte) cells. The results demonstrated that the fish collagen achieved by fermentation was non-toxic, and visibly stimulated the proliferation of HaCaT cells when compared to the control group [108].

Nile tilapia (*Oreochromis niloticus*) skin fermentation followed by extraction could also be applied as a time-saving and environmentally friendly method for obtaining fish-based collagen with a potential application in skin-care products [109].

The latest research by Costa et al. revealed that also by-products from the fermentation process can be applied as a sustainable and rich secondary source of bioactives with skincare potential, such as phenolic compounds and peptides. They applied engineered spent yeast (*Saccharomyces cerevisiae*) waste streams from the biotechnological production of β-farnesene. The results showed that the obtained peptide fractions had potential as possible future solutions for cosmetic applications, as they were not cytotoxic even at the highest concentration for the tested cell lines, namely human keratinocytes and primary dermal fibroblasts. Moreover, all peptide fractions showed a positive effect in the modulation of various cosmetically relevant metabolites (pro-collagen IαI, hyaluronic acid, fibronectin, cytokeratin-14, elastin, and aquaporin-9) [110].

3.4. Bioactive Compounds from Fruits Waste

Most of the fruit-based wastes and by-products arise after pressing the juice or after producing value-added products. Fruit waste after beverage production, namely pulp, skin, seeds, and stem mixture, take the form of pomace, which is very unstable [65]. Pomaces are most often used as biofertilizers (via composting) and as a potential source of biomass in the production of biofuels. However, because of their chemical richness and heterogeneity, they can also be used in the cosmetic industry as a source of active ingredients. In the non-edible parts of fruits (peels or twigs), the content of bioactive compounds, such as polyphenols, is often higher than in the edible parts (pulp) [65,73].

3.4.1. Citrus Waste

Citrus fruits, such as oranges, lemons, limes, grapefruits, and tangerines, are the most abundant fruit crop in the world. They are produced in an amount of 115 million tons per year. Over 30 million tons are industrially processed into juice, from which remaining 50% is waste, mainly in the form of citrus peels, and residues from segments and seeds after pressing [68,73,111]. Citrus peels are a rich source of essential oils, which are often produced directly in juice production plants as a co-product. Essential oils obtained from citrus peels have strong antimicrobial, antioxidant, and anti-inflammatory properties [55]. Tangerine peel extract can be combined within green biosynthesis to produce silver nanoparticles (AgNP's) [56]. After dropwise adding of the tangerine peel extract to the 1 millimolar solution of silver nitrate ($AgNO_3$) and stirring for few hours under dark conditions, a mixture with well dispersed AgNP's is created. It can also be used in cosmetic products due to the well-known antimicrobial properties of silver [56]. The ability of the ethanol extract of *Citrus unshiu* (mainly grown in Jeju Island, Korea) to inhibit melanin content, tyrosinase activity, and the protein expression profile of TRP-1, TRP-2, and MITF in murine melanocytes, was tested. The study confirmed that treatment with citrus pomace extracts significantly reduced the cellular melanin content by inhibiting tyrosinase activity and the transcription factors TRP-1 and TRP-2, and thus it can be used to reduce skin pigmentation disorders. Moreover, the essential oil of *Citrus unshiu* peels has anti-inflammatory and antimicrobial properties [55,103].

3.4.2. Banana Waste

Banana (*Musa sapientum*) is a tropical fruit that belongs to the *Musaceae* botanical family, and grows in more than 122 countries around the world. The annual production of bananas is 107.1 million tons, with 20% discarded due to the damage, inappropriate size, and other defects [111]. The main part of the banana that is suitable for reuse is the peels. Recently, banana peels have been used in various industrial applications, including biofuel, biosorbents, pulp and paper production, as well as energy-related activities, organic fertilizers, environmental cleaning, biotechnology-related processes, and ingredients of cosmetic products [112]. The main component of the green bananas peels is starch, which constitutes about 70–80% of the dry weight. However, this amount changes significantly during ripening due to the transformation of starch to fruit sugars [113]. The natural starch from banana peels has been used in the food, pharmaceutical, and cosmetic industries, minimizing the environmental problems related to this type of waste [113]. In the cosmetic industry, banana starch can be used as a thickening and gelling agent as well as a stabilizer to avoid phase separation in the emulsions. Starch also improves smoothness of the emulsions during application on the skin, and it can replace talc in formulations of face and body powders. The starch granule is a water-insoluble compound that acts as gelling and stabilizing agent. It can be hydrated at higher temperatures around 77 °C. It can be used in a maximum dose of 15% *w*/*w* in powder products [113]. Another raw material obtained from banana peel is extract. It has been confirmed in the literature that ethanol is the best solvent for the extraction of bioactive agents from banana peels. The high value added compounds present in banana peel extract include glycosides, alkaloids, saponins, carotenoids, biogenic amines, tannins, anthocyanins, epicatechin, catechin, flavonoids, phytate, and 18 different types of amino acids [112,114]. The banana peel extract also contains minerals such as iron, calcium, sodium, phosphorus, and magnesium. Moreover, it is a rich source of polyunsaturated omega-3 and omega-6 fatty acids, namely linoleic and linolenic acids [114]. It has antioxidant and anti-inflammatory properties. Banana peel extracts show firming, anti-aging, and skin brightening effects [112]. The antibacterial properties of banana peel ethanolic extract in both Gram-positive and Gram-negative bacteria, such as *Salmonella typhi*, *Bacillus subtilis*, and *Staphylococcus aureus*, have been confirmed by Ehiowemwenguan et al. [115]. The banana peel can also be used as a substrate to obtain lactic acid by fermentation process. Lactic acid is a valuable raw material in the cosmetic and pharmaceutical industry, serving as a pH adjuster and moisturising agent [112].

3.4.3. Mango Waste

Mango (*Mangifera indica* L.) processing waste is up to 40–50% by weight, with 20–60% of seed waste, which is a source of edible oil. Due to the fact that the fatty acid profile of mango is similar to that of cocoa butter and shea butter, it can be considered as a source of oleic, stearic, and palmitic acid [64,116]. Mango seed butter contains phenolic compounds and phospholipids, which gives it an anti-tyrosinase and antioxidant capacity [116]. The bioactive compounds present in mango peels are phenolic compounds, carotenoids, vitamin C, and dietary fibres [78]. Additionally, mango peels are a very good substrate for the preparation of lactic acid. Among the peels of many fruits, such as orange, mango, banana, and pineapple that were subjected to lactic fermentation by *Lactoctobacillus plantarum* as the starter culture, the highest amount of lactic acid (10.08 g/L) was obtained from the mango peel [112].

3.4.4. Apple Waste

Apple (*Malus domestica* Borkh.) is a widely consumed and well-recognized fruit, and its global production exceeds 83 million tons. A large portion of apple production is converted into value-added food products, such as processed juice or cider, in which about 25% of the weight of fresh fruits is a pomace by-product. Apple pomace constitutes an important source of pectins, which are widely used in the food, cosmetics, and pharmaceutical industries as a natural thickener, gelling agent, and stabilizer [65,73]. Apple pomace contains active compounds such as triterpenoids, phenolic acids, flavanols, flavanols, flavones, anthocyanins, dihydrochalcones, and hydroxycinnamic acid, quite often in amounts higher than in the whole fruit [117]. Extracts of apple pomace possess antioxidant, antibacterial, and anti-inflammatory properties, so they can be of great help in maintaining a healthy skin condition. In addition, they contain polyphenols, which inhibit specific pro-inflammatory mediators such as nitric oxide, inducible nitric oxide synthase, reactive oxygen species

(ROS), cytokines, prostaglandins, or cyclooxygenases, and eliminate the inflammation process in the skin [117]. The in vitro study validated the inhibition capacity of apple-based phenols in sebum production in sebaceous glands, which alleviated skin diseases such as acne. Several in vitro and in vivo studies have also reported the positive effects of apple pomace phenolic compounds on skin damages such as wounds or burns, premature skin aging, psoriasis, rosacea, and atopic dermatitis [117].

3.4.5. Avocado Waste

Avocado (*Persea americana* Mill.) is a tropical and subtropical fruit that is grown mainly in Mexico and Central America. The pulp of this fruit contains insoluble (70%) and soluble (30%) fibres, lipids, mainly glycolipids and phospholipids, monounsaturated fatty acids, and proteins in quantities greater than in many other fruits [118]. Moreover, avocado pulp contains sugars and proteins, as well as pigments, tannins, polyphenols, phytoestrogens, and perseitol [118]. The high oil content is particularly important, as it contains monounsaturated fatty acids (oleic and palmitoleic acids), low quantities of polyunsaturated fatty acids (linoleic acid), and a significant quantity of saturated fatty acids (palmitic and stearic acids), with small proportion of myristic, linolenic, and eicosenoic acids [118]. Another important component of avocado pulp are minerals, especially high amounts of potassium and less of phosphorus, magnesium, calcium, sodium, iron, and zinc. Vitamins, such as β-carotene, vitamin E, retinol, ascorbic acid, thiamine, riboflavin, niacin, pyridoxine, and folic acid are also present [56]. About 20–30% of the processed avocado pulp consisting of seeds, peels, and exhausted pulp from the extraction of avocado oils is discarded as waste [118]. These residues contain mainly carbohydrates, such as fibres, hemicellulose, and starch, and have a great antioxidant capacity due to the high content of polyphenols such as quercetin glycosides, type A and B procyanidin dimers, type A procyanidin trimers, catechin, caffeoylquinic acid, and coumaroylquinic acid. Because of the low cost and great properties, avocado residues are potential source of oils, essential oils, and fibres for use in the food, cosmetic, and pharmaceutical industries [118]. Avocado residue extracts possess antioxidant, anti-inflammatory, and antimicrobial properties against Gram-positive and Gram-negative bacteria (*Salmonella enteritidis*, *Citrobacter freudii*, *Pseudomonas aeruginosa*, *Enterobacter aerogenes*, *Staphylococcus aureus*, *Escherichia coli*, *Mycobacterium*, *Listeria monocytogenes*), and also antifungal properties (against *Candida* spp., *Cryptococcus neoformans*, and *Malassezia*); therefore, it can be used in cosmetic formulations. Moreover, fatty alcohols extracted from the seed and pulp of avocados have photo-protective properties against UV induced damage in skin cells [118].

3.4.6. Olive Waste

The annual production of edible olive oil from *Olea europaea* L. is about 3.26 million tons [70]. This generates 4.5 million tons of by-products, such as the wastewater of the olive mill, the pomace, the leaves, branches, and seeds, which are rich in fatty acids, tocopherols, polyphenols, phytosterols, and squalene [79,111]. The waste from the olive industry is a greater source of polyphenols than the olive oil itself [79]. The main phenolic compounds in olives are as follows: hydroxytyrosol, tyrosol, oleuropein, verbascoside, and their derivatives, which have powerful antioxidant activity in both vivo and in vitro studies [55,79,119,120]. Moreover, hydroxytyrosol and oleuropein have anti-inflammatory, anti-atherogenic, antimicrobial, and antiviral properties. These compounds are soluble in water, and thus only a low percentage dissolves in the lipidic fraction of the olives. Rich in hydroxytyrosol aqueous olive extract inhibited the production of inflammatory mediators, such as nitric oxide (NO) and prostaglandin E2 (PGE2) cytokines, as well as chemokines [55]. Olive polyphenols may contribute to the skin photoprotection as a booster of UV filters. They increase the sun protection factor (SPF) and UVA absorption when combined with UV filters, such as TiO_2, benzophenone-3, diethylamino hydroxybenzoyl hexyl benzoate, methylene bis-benzotriazolyl tetramethylbutylphenol, octocrylene, octylmetoxycinnamate, and octyl dimetyl para-aminobenzoic acid (OD-PABA) [79,119,120].

Due to the antimicrobial properties of olive derivatives, they can be used in cosmetics as preservative boosters. Phenolic compounds found in olive wastes, like olive leaf extract, pomace, and oil industry by-products extracts, have antimicrobial activity against *Escherichia coli*, *Salmonella entérica*, *Pseudomonas aeruginosa*, *Bacillus cereus*, *Staphylococcus aureus*, and *Bacillus subtilis* [79,119,120]. Lipophilic compounds from olive waste have emollient, moisturizing, and protective properties, and they repair the function of the skin lipid barrier. They have capacity to remain on the surface of the skin for long periods of time and act as lubricants. Also improvement in the condition of the skin impact with dermatosis, such as atopic dermatitis, psoriasis, eczema, and very dry skin could be observed after applying cosmetic formula containing olive wastes, giving the sensation of soft, elastic, and hydrated skin [79,119]. Olive wastes are rich in fatty acids, especially oleic acid, and essential polyunsaturated fatty acids (EFAs) such as linoleic (C18:2) and linolenic (C18:3) acids, which have anti-irritant and anti-inflammatory effects and replenish the lipids of the skin epidermal barrier [79]. *Olea europea* is also the main source of squalene, which is a lipid from the family of triterpene, being the most abundant on the skin's surface and possessing emollient, antioxidant, antibacterial, and antifungal properties [79,119,120]. Olive waste such as pomace, olive leaves, and oil industry by-product extracts may also serve as a source of natural vitamin E, mainly α-tocopherol, which is non-enzymatic antioxidant. The leaves of *Olea europea* contain carotene, which is a natural pigment with high antioxidant capacity. Rich-in-carotene olive waste extract used topically on the skin reduces free radicals, prevents UVA damage in the skin cells, and shows anti-inflammatory effects [79,119,120].

3.4.7. Grapes Waste

Grapevine (*Vitis vinifera* L.) is a fruit crop used for fresh consumption and production of wine, juice, dried fruits, and distilled liquor. Approximately 80% of its production is destined for winemaking by pressing and macerating grapes, which in Europe creates approximately 4.5 million tons of wastes per year [121]. Grape pomace is composed of grape seeds (25%), stalks (25%), and skins (50%). It has low pH, high organic carbon content, and significant concentration of phenolic compounds. Due to this fact, it can resist biological degradation and cause unbalance in the ecosystem. The extraction process is an effective method of grape waste valorisation, resulting in raw materials with antioxidant, antimicrobial, and anti-inflammatory properties [121,122]. For the needs of the cosmetic industry, extracts are obtained from seed and oil, pomace, grape skins, shoot, stalk lees, stem cells, and seed paste. Grape pomace by-product contains unsaturated fatty acids, dietary fibres, vitamins, and natural antioxidants, especially polyphenols such as phenolic acids (hydroxybenzoic, hydroxycinnamic acids), flavonoids (catechin and epicatechin), stilbenes (trans-resveratrol), tannins, and proanthocyanins [123]. Grape seeds and grape pomace can also be used as raw materials to obtain oils composed of unsaturated fatty acids, like linoleic acid (which accounts about 70–75% of total oleic fraction), oleic acid, and palmitic acid [122]. Due to the low content of linolenic acid, grape seed oil has longer durability. Grape seed oil is also rich in tocopherols (α, β, γ, δ) and tocotrienols (α, β, γ, δ) [122,124]. Both grape extract and grape seed oil as a by-product from the grape waste give a beneficial effect on the skin. Grape seed extract has antioxidant, anti-tyrosinase, anti-ageing, anti-microbial (against *Staphylococcus aureus* and *Staphylococcus epidermidis*), antifungal, anti-acne, and anti-inflammatory activity, and protects skin cells against UVA damage [121,122,124]. Moreover, grape seed oil has antioxidant and antimicrobial activities, whereas grape seed powder has an abrasive and exfoliant properties [121,122,124].

3.4.8. Pomegranate Waste

Pomegranate (*Punica granatum* L.) is a fruit used in in the food industry for juice extraction. Pomegranate's rind and seeds, which account for roughly 54% of the fruit, are the waste components rich in bioactive compounds with antioxidant and antimicrobial activity, and therefore they can be converted to various value-added products [125,126]. Global pomegranate production reaches 3 million tons per year, resulting in approximately

1.62 million tons of waste rich in bioactive and nutritional components, such as flavonoids (e.g., anthocyanins), hydrolysable tannins (e.g., punicalagin and ellagic acid), and fatty acids (mainly punicic, linoleic, oleic, stearic, and palmitic acid). Pomegranate oil is extracted from pomegranate seeds and has anti-inflammatory properties. It is also effective in fighting against UV-induced stress, both in tested animal skins and in vitro models [125]. Pomegranate extracts and oil have antibacterial, antifungal, anti-inflammatory, and anti-pain properties; they also enhance the healing process of burns and wounds by increasing collagen content in cells. Whitening effect on skin pigmentations caused by UVB irradiation has been proved, as well. It is the results of high content of ellagic acid, which also has an anti-aging effect against skin wrinkling, and can increase skin elasticity due to the inhibition of the glycation process [125,126].

3.4.9. Coffee Waste

Around 103 million tons of coffee are produced worldwide every year, resulting in about 18 million tons of wet, spent coffee grounds [52,111,127–129]. The residues that remain after coffee brewing are one of the most wide-spread by-products which can be reused. The chemical composition of the coffee waste includes polyphenols and tannins, which total amount represent around 6% and 4%, respectively. It has been proved that 60% methanol is the best solvent in the extraction process leading to the highest amounts of gallic acid equivalents per gram of spent coffee grounds [78]. The waste from the coffee industry, namely pulp, husks, grounds, and unripe coffee beans, can be processed into cosmetic raw materials. The coffee grounds can be use as scrub for body care [111]. They also contain high amounts of lipids which can be extracted by supercritical carbon dioxide extraction process and subsequently used in cosmetic formulations improving skin hydration [56]. Moreover, coffee is a good source of bioactive compounds such as chlorogenic acids, caffeine, melanoidins, and other antioxidants [56]. These active ingredients show anti-inflammatory, antimicrobial, and anti-cellulite properties, improve blood circulation in the small capillaries, and protect skin cells against UV damage [56,111,127–129]. Coffee extract can be used in anti-aging cosmetics, as well as in shampoos and conditioners, to stimulate hair growth on the scalp [127–129].

3.5. Bioactive Compounds from Vegetable Waste

Vegetables establish an important source of active ingredients which may also be found in the inedible parts, such as leaves, twigs, or stems. Common vegetables like potatoes, tomatoes, carrots, broccoli, or cucumbers have been extensively used in the food industry, generating enormous amounts of waste which can be further processed into cosmetic raw materials [130].

3.5.1. Tomato Waste

Tomatoes (*Solanum lycopersicum*) contain high amounts of bioactive compounds such as carotenoids, fibre, proteins, and pectins. Tomato seeds are one of the most abundant residues due to a large production of tomato sauce. On a global scale, the annual production of fresh tomatoes accounts to approximately 160 million tons [55]. This vegetable is rich in fatty acids, especially linoleic acid. On the other hand, tomato peel contains lycopene, which is a strong antioxidant [64]. Tomatoes have already been proved as vegetables with high antioxidant potential due to the presence of polyphenols, which are located specifically in the peels [130]. The example is lycopene, whose concentration is up to five times higher in the waste peels than in the pulp. In order to increase the efficiency of lycopene extraction, tomato peels are subjected to enzymatic pre-treatment with pectinolytic enzyme preparations followed by surfactant-assisted extraction [55,131].

3.5.2. Carrot Waste

Carrot (*Daucus carota* L.) is an important vegetable source of bioactive compounds, with a worldwide production of more than 37 million tons every year [132–134]. Carrot processing generates waste in the form of peels and pomaces, which contain high amounts of residual bioactives, mainly carotenoids (with about 50% of β-carotene), phenolics, polyacetylenes, ascorbic acid, terpenoids, and tocopherols. Carotenoids, especially apocarotenoids, have characteristic orange colour, so they can be used as natural colourant and aroma in cosmetic products [132,133]. Oil and water extract of carrot pomace has good anti-inflammatory and antioxidative properties due to the presence of β-carotene, lutein, and zeaxanthin, and gives anti-aging effects due to the free-radical scavenging [134,135].

3.5.3. Potato Waste

Potato (*Solanum tuberosum* L.) is the fourth main crop produced globally, after rice, wheat, and corn, with over 388 million tons every year. This generates a large amount of wastes, such as peels and pulp. Potato by-products have antimicrobial, antioxidant, and anti-inflammatory properties [130,136]. Potato peel is a source of bioactive compounds; it contains much higher amounts of phenolic compounds than the tuber (the inner part of the vegetable). Phenolic acids from potato peels, mainly chlorogenic acid, have antioxidant and antibacterial properties, while glycoalkaloids have anti-carcinogenic potential via the induction of cytotoxicity and apoptosis in cancer cell lines [136]. Good antioxidant activity also forms a residue from the process of starch extraction, which can be a source of pectins. It is also possible to obtain biosurfactants from potato peels and pulp waste by using mutated *Bacillus subtilis* DDU20161. Such biosurfactants have lower toxicity, higher biodegradability, and show effectiveness at extreme temperatures, salinities, and pH values when compared with synthetic ones. This green alternative to synthetic surfactants can be used in the cosmetic industry as well [137]. Moreover, potato peel can be transformed to lactic acid through the fermentation process [138].

Currently, a lot of research is being conducted on the possibilities of managing waste from the food industry in order to obtain valuable row materials for cosmetics formulations. Table 3 shows selected examples of results of such studies that have been published in the last few years.

Table 3. Bioactive compounds from by-products and wastes in fruit and vegetable processing.

Source of Food Waste	Type of Waste	Cosmetic Ingredients	Bioactive Components	Properties	Refs.
Citrus fruit	Peel, Pulp, Seeds	Extracts, active powder, peeling	Phenolic acids (hydroxybenzoic acid, caffeic acid), flavones (apigenin-glucoside, diosmetin-glucoside), flavanones (hesperidin, naringin, eriocitrin, narirutin)	Antioxidant, anti-inflammatory, anti-bacterial	[88]
Grapes	Seeds and peels	Extracts, Oil	Coumaric acid, caffeic acid, ferulic acid, chlorogenic acid, cinnamic acid, neochlorogenic acid, p-hydroxybenzoic acid, protocatechuic acid, vanillic acid, gallic acid, proanthocyanidins, quercetin 3-o-gluuronide, quercetin, stilbenes (resveratrol)	Antioxidant, anti-inflammatory, antimicrobial against Staphylococcus aureus, sun protection factor (SPF) booster, anti-tyrosinase activities (skin whitening), anti-elastase, anti-collagenase activities (anti-aging), cellular protective effect against oxidative damage, anti-acne	[121,122,124]
Banana	Peels, Pulp	Extracts, powder starch	Gallocatechin, anthocyanins, delphindin, cyaniding, catecholamine	Starch: thickener, stabilizer, gelling agent	[112–114]
Mango	Peels and kernel	Extracts, butter	Gallic acid, ellagic acid, gallates, gallotannins, condensed tannins, quercetin, isoquercetin, fisetin, mangiferin	Antioxidant, anti-bacterial, hydrating, reducing transepidermal water loss (TEWL)	[78,116,139]

Table 3. *Cont.*

Source of Food Waste	Type of Waste	Cosmetic Ingredients	Bioactive Components	Properties	Refs.
Apple	Peels and pomace	Extracts, emollients, active powder	Pectins, epicatechin, catechins, anthocyanins, quercetin glycosides, chlorogenic acid, caffeic acid, ferulic acid, hydroxycinnamates, phloretin, glycosides, procyanidins, triterpenoids (ursolic acid, oleanolic acid)	Pectins: thickener, stabilizer	[117]
Pomegranate	Peels and pericarp	Extracts, oil	Gallic acid, cyanidin-3,5-diglucoside, cyanidin-3-diglucoside, delphinidin-3,5-diglucoside	Anti-inflammatory, anti-pain, burn wound healing, whitening, antibacterial, antifungal, anti-aging, inhibition of glycation	[125,126]
Avocado	Peels and seeds	Extracts, oil	Epicatechin, catechin, gallic acid, chlorogenic acid, cyanidin 3-glucoside, homogentisic acid	Antioxidant, anti-inflammatory, anti-microbial, anti-fungal, photo-protective	[118]
Olive	Leaves, pomace, seeds	Extracts, oil	Pectins and oligosaccharides, sugars: mannitol, cellulose, hemicellulose; phenols and polyphenols, triterpenes, fatty acids, squalene, essential amino acids, malonic acid, carotenoids, tocopherols, minerals (K, Ca, Na)	Pectins, oligosaccharides: Improvement in physical/structural properties of emulsions, oxidative stability, viscosity, texture, sensory characteristics, and shelf-life of products	[79,119,120]
Carrot	Pomace	Extract, oil	Phenols, β-carotene	Antioxidant, anti-ageing, colorant, aroma	[132–135]
Potato	Peels	Extract	Gallic acid, caffeic acid, vanillic acid, pectins, chlorogenic acid, carotene, lycopene, lutein	Antioxidant, anti-microbial, anti-inflammatory	[130,136,137]
Tomato	Seed, pomace	Extract, oil	Carotenoids (lycopene), phenolic acids, chlorogenic acid, gallic acid, ferulic acid, quercetin	Antioxidant, anti-inflammatory, antifungal	[131]
Coffee	Grounds, pulp, husks, beans	Extracts, peeling	Polyphenols, tannins, chlorogenic acids, caffeine, melanoidins	Anti-inflammatory, antimicrobial, anti-cellulite, improvement in blood circulation	[127–129]
Hazelnuts	Skin and roasted husk	Extract	Phenolic compounds (proanthocyanidins A and B)	Antioxidant, antifungal	[140]

3.6. Bioactive Compounds from Animal Waste

Bioactive compounds isolated from animal-based waste include mainly peptides. In the dairy industry, it is mainly those from whey and colostrum [65,141]. Whey is the main by-product obtained during cheese production from all types of milk, namely goat, sheep, camel, buffalo, and, most commonly, cow milk [138]. Whey contains about 55% of milk nutrients, such as proteins, β-lactoglobulin, α-lactalbumin, bovine serum albumin, immunoglobulins, and macropeptides. Every year, approximately 300–320 million tons of whey ends up in wastewaters [141]. However, during the purification procedure specific fractions from whey may be obtained. Lactose from whey can be fermented to produce biomass and lactic acid, which can be used as cosmetic ingredients. Moreover, protein-rich fractions are reused and applied as cosmetic raw materials with ability to counteract skin damage, preserve skin integrity, and reduce drawbacks related to the dermal dryness [138].

In the marine sector, bioactives could be obtained from fish and shellfish processing, as well as from seaweeds [65,142,143]. Hot-water extraction of pulverized oyster shell gives polypeptides with tyrosinase inhibitory activity; therefore, it can be used as an ingredient of cosmetics that lighten skin discolorations [68,142]. Shrimp and crab shells can be recovered for obtaining chitosan, which is a natural polymer used in the skin and hair care. It has antibacterial, antioxidant, protective, smoothing, and soothing properties. It also shows the ability to accelerate skin regeneration processes, so it could be used in the production of wound-dressing materials [144]. Furthermore, calcium carbonate from oyster shells can be used as a calcium supplement [68,142]. On the other hand, astaxanthin is a chromophore that can be extracted from shrimp shells. It has strong antioxidant properties with an efficacy of 500 times higher than that of vitamin E; thus, astaxanthin can be used in anti-ageing cosmetic products [145]. Collagen from fish waste, such as skin, bones, and scales, has nutraceutical, cosmeceutical, and bio-medical applications because it is a source of many amino acids. It also possess antioxidant, antimicrobial, and anti-aging properties, which are highly desirable in the cosmetic industry [146,147].

3.7. Bioferments

Bioferments are raw materials obtained using a fermentation process carried out with appropriate strains of microorganisms, such as bacteria and/or yeast (Figure 4). Processing food waste by microorganisms is a sustainable and eco-friendly solution in food waste management. It may generate biofuels, electrical energy, biosurfactants, bioplastics, and biofertilizers, and also cosmetic raw materials such as prebiotics and postbiotics, fermented extracts, or fermented whey. Microbial fermentation can be used in processing of crops, fruits and vegetables, dairy products, edible oil, meat, poultry, eggs, sea food, and other aquatic organisms [148,149]. Microbial processing of food waste has opened new horizons for value addition to conventional extraction [148]. It needs renewable feedstock, such as biomass, and requires mild conditions of temperature and pressure to carry out the process, giving a lower environmental footprint than conventional chemical synthesis [27]. Many fermented products and fermentation by-products have already been introduced to the market, including fermented beverages, single cell proteins, single-cell oils, polysaccharides, dietary fibres, polyphenols, bio-pigments (carotenoids), fragrances, flavours (vanillin), essential oils, biopesticides, plant growth regulators, and enzymes. Biohydrogen, bioethanol, and biogas are also produced from waste of fruits and vegetables containing starch, cellulose, and hemicelluloses, which are at first hydrolysed to soluble sugars and further fermented [148,149].

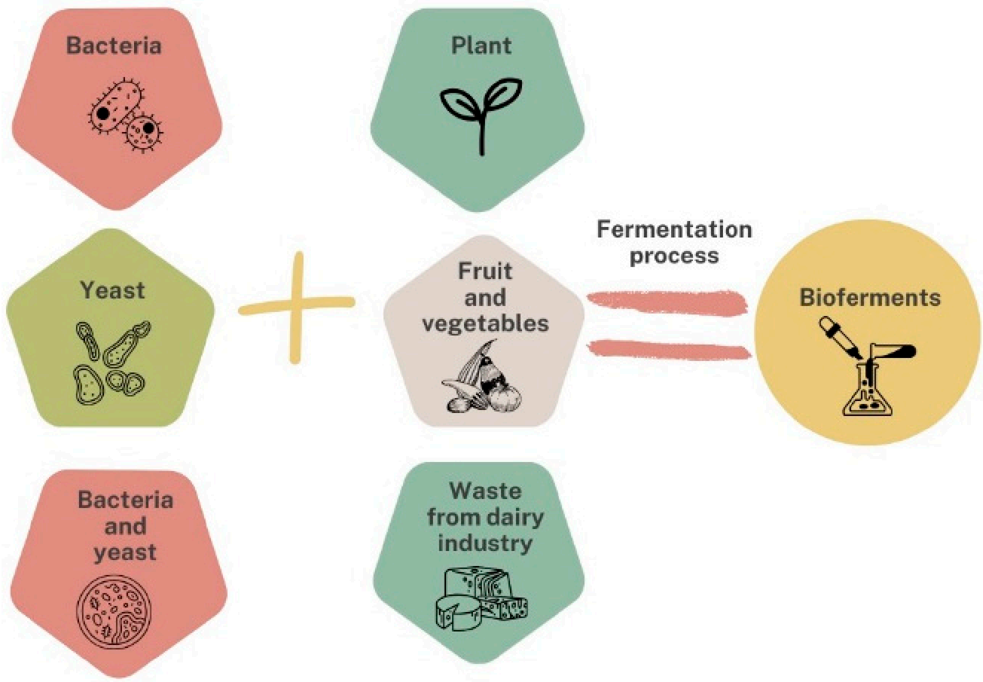

Figure 4. Schematic representation of the biofermentation process.

3.8. Bioferments in the Cosmetic Industry

For the needs of the cosmetic industry, fermented raw materials are obtained from plants, fruits, vegetables, oils, and substrates from the dairy industry. The use of ingredients derived from wastes generated by the food and dairy industry, as well as from plant-based biomass, allows for resourcing, reducing of carbon footprint, and supports the circular economy [98,150]. Due to the fact that fermentation converts high-molecular compounds into low-molecular structures, the bioavailability of ingredients is significantly higher [98]. Moreover, specific microbial strains used in the fermentation process produce additional active substances such as proteins, ceramides, amino acids, acids, and antioxidants, thanks to which the final raw material shows increased bioactivity and biocompatibility [150,151]. The efficiency of the fermentation process and content of bioactive ingredients depends on the type of microorganism strains and conditions under which the process is carried out [98]. During the fermentation process, metabolites of bacteria and yeast are formed, such as malic, fumaric, and citric acids, which are intermediates in the Krebs cycle and act as rapid energy substrates for skin-cell mitochondria [27]. Fermentation-derived ingredients have many advantages when compared to those obtained by conventional chemical synthesis. First of all, the fermentation process uses renewable sources as substrates and requires mild processing conditions. Moreover, it reduces waste, and the obtained products are biodegradable [27,99]. The use of fermented raw materials also has many benefits for the skin [152]. Due to the smaller molecular structures of active substances in fermented raw materials, antioxidant and anti-inflammatory properties may be increased by improved bioavailability [149,152–154]. Bioferments in cosmetic products may stimulate natural skin defence mechanisms, reduce consequences of photodamage, whiten the skin, help in rebuilding the skin barrier, support the wound healing process, reduce the symptoms of acne, and protect the skin against pollution and oxidative stress [92,155]. It is worth mentioning that fermentation is also used in order to obtain biosurfactants from kitchen waste oil, whey, utilized soy molasses, and olive oil mill waste. Biosurfactants, unlike surfactants produced in the chemical synthesis, are fully biodegradable and non-toxic to aquatic organisms [148]. Examples of current studies on fermented plants, fruits, vegetables, and dairy products serving as bioferments with cosmetic applications are presented in Table 4.

Table 4. Cosmetic properties of fermented raw materials from plants, fruit, vegetables, as well as dairy and marine industry by-products.

Raw Material	Microorganisms	Properties	Refs.
Citrus unshiu peel	*Schizophyllum commune* QG143	Anti-aging, anti-photoaging	[103]
Lemon peel	*Lactobacillus lactis*	Skin whitening, reduction of discoloration, antioxidant	[156]
Goji berry (*Lycium barbarum* L.)	*Lactobacillus rhamnosus*, *Lactobacillus reuteri*, *Bacillus velezensis* or *Lactobacillus rhamnosus*, *Lactobacillus plantarum*, *Bacillus velezensis*, *Bacillus licheniformis*	Anti-oxidant, anti-aging, skin whitening	[157]
Plum pomace and seeds	*Aspergillus niger* and *Rhizopus oligosporus*	Anti-oxidant, moisturizing	[158]
Camellia sinensis (Miang tea)	*Lacticaseibacillus rhamnosus*, *Lactiplantibacillus plantarum*, *Saccharomyces cerevisiae*	Anti-oxidant, tyrosinase inhibition (skin whitening), reduction of discoloration, collagenase inhibition (anti-aging)	[159]
Jasminum sambac flowers	*Lactobacillus rhamnosus*	Antioxidant, anti-aging, anti-photoaging induced by UVB radiation,	[160]
Angelica gigas, *Lonicera japonica*, *Dictamnus dasycarpus* Turcz., *D. opposita* Thunb., *Ulmus davidiana var. japonica*, *Hordeum vulgare var. hexastichon* Aschers., *Xanthium strumarium* L., *Cnidium officinale*, *Houttuynia cordata* Thunb.	*Lactobacillus fermentum*	Protection against UVB-induced damage, anti-inflammatory	[161]

Table 4. *Cont.*

Raw Material	Microorganisms	Properties	Refs.
Soybean	*Bifidobacterium animalis*, *Saccharomyces cerevisiae*, *Bacillus subtilis*	Improved skin hydration and elasticity, anti-oxidant, skin whitening and reduction of discoloration	[162]
Red ginseng	*Lactobacillus brevis*, *Saccharomyces cerevisiae*	Anti-wrinkle, skincare, anti-inflammatory, anti-allergenic	[27,151]
Red ginseng marc	*Lactobacillus casei*, *Saccharomyces cerevisiae*, *Rhodobacter capsulatus*	Promoting effects on the hair growth cycle	[163]
Carrot root	*Bacillus gingsengisoli*	Anti-oxidant, reduced skin dullness, anti-aging, anti-wrinkle	[132]
Radish root	*Lactobacillus casei*	Anti-oxidant, anti-aging, healing of damaged cells, toxin removal, skin nourishing	[148]
Wine industry by-products	Kombucha SCOBY (Symbiotic Cultures of Bacteria and Yeasts) consortium	Moisturizing, anti-oxidant, anti-aging	[164]
Agro-industrial waste cane molasses	*Streptococcus zooepidemicus* MTCC 3523	Moisturizing, anti-aging	[165]
Whey	*Leuconostoc mesenteroides*, *Lactobacillus jensenii*, *Lactobacillus acidophilus*	Antioxidant, anti-inflammatory	[166]
Yogurt whey	*Lacticaseibacillus casei*	Increased production of lactic acid, hydrating properties	[166]
Waste shrimp shells	*Paenibacillus jamilae* BAT1	Antimicrobial and antioxidant	[167]

In general, the fermentation process uses microorganism to increase the biochemical and physiological activity of the substrate by converting high-molecular compounds into low-molecular structures. Microorganisms are biocompatible, and very often they simplify the synthesis, improve and give consistent quality of products, and reduce the environmental footprint. Many biological molecules may be involved, directly or indirectly, in the production of various fermented raw materials with valuable compounds, such as polyphenols, carotenoids, fatty acids, enzymes, or vitamins.

The chemical composition and quality of raw materials obtained using fermentation depends on many factors, but primarily depends on the type of microorganisms used. In the case of cosmetic raw materials, obtaining biosurfactants containing fatty acids, glycolipids, neutral lipids, and lipopeptides can occur in the presence of the following strains of fungi and bacteria: *Pseudozyma antarctica*, *Pseudozyma aphidis*, *Pseudozyma rugulosa*, and *Pseudozyma parantarctica*, as well as *Bacillus pumilus* A, *Bacillus licheniformis*, *Bacillus amyloliquefaciens*, and *Bacillus subtilis*. On the other hand, glycosylides are mainly produced by *Candida albicans*, *Agaricus bisporus*, and *Armillaria tabescens*. Biosynthesis with strains like *Bacillus subtilis* 313, *Brevibacterium* sp. Strain 9605, Brevibacillus brevis CD 162, and *Microbacterium terrae* KNR 9 allows us to obtain cyclodextrins, which are a group of compounds often used in cosmetic products as fragrance-stabilizing agents. The *Saccharomyces cerevisiae* strain is used in obtaining ceramides of microbial origin [98]. *Paracoccus*, *Agrobacterium aurantiacum*, and *Corynebacterium autotrophicum* are bacterial strains applied in the synthesis of cosmetic pigments like astaxanthin and zeaxanthin, respectively. In turn, *Leuconostoc mesenteriodes*, *Streptococcus mutans*, *Pseudomonas aeruginosa*, and *Azotobacter vinelandii*, *Xanthomonas* spp., *Sinorhizobium meliloti* M5N1CS, *Gluconacetobacter hansenii*, and *Streptococcus thermophilus* are responsible for the bioengineered synthesis of exopolysaccharides like dextran, alginate, xanthan, glucuronan, and hyaluronic acid. Furthermore, bacteria like

Clostridium histolyticum, *Vibrio alginolyticus*, *Bacillus cerus*, *Microsporum*, *Epidermophyton*, *Trichophyton*, *Chrysosporiu*, *Scopulariopsis brevicaulis*, *Bacillus subtilis* and *Bacillus licheniform*, *Sulfolobus acidocaldarius*, *Marinomona*, and *Thermus thermophilus* have been proved to be an effective tool in fermentation leading to different enzymes with high cosmetic values, namely collagenases (skin regeneration) and keratinases (excess hair removal), as well as superoxide dismutase, catalases, and glutathione peroxidase (antioxidants, free radical scavenging, anti-aging) [168].

In order to ensure the repeatability of the composition of a given bioferment, it is necessary to optimize the parameters of the fermentation process, such as pH, temperature, appropriately selected bacterial strains, and the duration of the fermentation process. Then, the obtained bioferment should be subjected to a detailed analysis in terms of composition, which can be performed using chromatographic methods. Particular attention should be paid to the content of biogenic amines, methanol, formaldehyde, and nitrites. If they occur in the bioferment, additional techniques should be applied to support their removal, e.g., appropriate enzymes or bacteria strains decomposing those chemicals should be introduced [27]. The allergenic potential of bioferment is usually assessed by the Safety Assessor. The tests are based on the toxicological assessment of the ingredients of bioferments, and then are performed as dermatological patch tests. Nevertheless, it should be emphasise that fermentation of plant raw materials is widely used in the food industry, and the allergenic potential of these products is low [169].

4. Summary and Future Directions

The main pillars of the Green Deal which apply to the cosmetics industry are circular economy and zero pollutions, which means reduction in the greenhouse gas emission, assurance of resource efficiency in a circular economy, the protection and restoration of ecosystems, and biodiversity. The answer to these expectations is using waste from the food industry to produce valuable raw materials that can be applied in the cosmetic industry, for example. This solution allows reducing carbon footprint and has a large potential for improving circularity in the food system. It also offers new opportunities to create sustainable raw materials for the cosmetics industry. Upcycling of food industry waste is not only advantageous to the environment, but also provides many bioactive ingredients that have a beneficial effect on the skin. Wastes from fruits and vegetables such as peels, seeds, grounds, and pomace often contain higher amounts of bioactive compounds when compared to the pulp. Polyphenols, vitamins, and minerals and can be effectively extracted by environmental friendly procedures and used as cosmetic raw materials.

Despite many advantages of compounds obtained from food waste, there are still some challenges related to the waste processing. It is necessary to develop efficient methods of extraction, purification, and characterization in order to obtain the valuable active compounds from the waste materials. Another challenge is to create scalable production methods with reproducible batches of extracts. This is due to the variability of the composition of agri-food waste, which affects the composition as well as quality and quantity of the extracted compounds.

Application of bioferments is the innovative trend in the cosmetics industry that does not bring any negative impact on the environment. Fermentation can provide the cosmetic industry with countless alternatives, replacing controversial ingredients. Thanks to fermentation, it is possible to obtain not only cosmetic active ingredients, such as ubiquinol, resveratrol, or hyaluronic acid, but also very common ingredients such as thickeners, preservatives, emollients, humectants, and biosurfactants. Active substances obtained during fermentation process show increased bioactivity and biocompatibility, and present good biodegradability profile.

The fermentation process of plant-based materials involves several risks, including the possibility of producing potentially toxic compounds as by-products, namely biogenic amines, methanol, formaldehyde, and nitrite. Moreover, the constant control of microbial safety, the lack of trace elements, and storage stability is necessary. To reduce the risk of biogenic amines production, microbial strains or enzymes that decompose these compounds should be used. To reduce the content of methanol and formaldehyde, the temperature of the fermentation process should be optimized.

Although bioferments have been shown to have a beneficial effect on the skin, there is still little research in this direction, and the development of new testing methodology still need to be addressed. It is expected that, in the next coming years, the use of extracts based on upcycled raw materials and bioferments will constantly increase. Therefore, research on the effectiveness of fermented raw materials on skin cells should also be intensified in order to confirm skin nourishing effects.

Author Contributions: Conceptualization, M.K., A.W. and I.N.; resources, M.K., writing—original draft preparation, M.K.; writing—review and editing, A.W. and I.N.; visualization, M.K.; supervision, A.W. and I.N. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: Author Monika Krzyżostan was employed by the company Dr Koziej Instytut Badań Kosmetyków. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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