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Biomaterials in Cosmetics and Personal Care Industry: A Comprehensive Literature Review and Case Studies

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Abstract

This thesis aims to present a detailed analysis of the most commonly used and studied biomaterials in the cosmetics and personal care industry. To deeply understand the biomaterial concept in cosmetics, a comprehensive literature review has been conducted and findings of past research have been listed. 19 biomaterials that have plant, animal, and other biological organism origins have been selected as representatives to examine the biomaterial concept in the target industry. The functions and benefits of each material in a cosmetic context, their processing methods, advantages, disadvantages, and real market examples have been listed in separate sections. Then, the development status of each biomaterial has been discussed from a comparative perspective and with the support of the quantitative data related to biomaterials' environmental footprint. Patents, certifications, and relevant case studies of sustainable beauty and upcycling companies have been added to support scientific research with real industry applications. Finally, packaging options and materials in the cosmetics industry have been briefly discussed to increase the overall sustainability of products.

All research findings supported that biomaterials are highly useful in the cosmetic industry and preferred both by producers and customers. Being biodegradable, biocompatible, and having a low carbon and water footprint are the main positive aspects that make biomaterials appropriate in this industry's products. While plant-based biomaterials are considered more amicable for most customers, animals and other bioorganisms are also commonly used as sources for bio-cosmetics. Processing methods that are being used to obtain cosmetic ingredients from biomaterials are diverse, and recently more sustainable processing technologies are being developed, which are scarce of chemicals and inorganic solvents. Case studies and many granted patents listed support the scientific research findings by showing the real applications of biomaterials in cosmetic formulations. To summarize, this study combines theoretical knowledge and real-life cases of biomaterials in the cosmetic sector, with the help of comparative reviews, both quantitative and qualitative data, and a variety of sources. There are several limitations in this study, but it is still a good comprehensive review of the relevant topic that could help as a source for future studies.

Keywords: Biomaterials, bio-based materials, cosmetics, personal care, plant-based materials, animal-based materials, development status of biomaterials, LCA of bio-based materials

Riassunto

Questa tesi si propone di presentare un'analisi dettagliata dei biomateriali più comunemente utilizzati e studiati nel settore dei cosmetici e della cura personale. Per comprendere a fondo il concetto di biomateriale nei cosmetici, è stata condotta una revisione completa della letteratura e sono stati elencati i risultati delle ricerche passate. 19 biomateriali di origine vegetale, animale e di altri organismi biologici sono stati selezionati come rappresentanti per esaminare il concetto di biomateriale nel settore di destinazione. Le funzioni e i vantaggi di ciascun materiale in un contesto cosmetico, i metodi di lavorazione, i vantaggi, gli svantaggi e gli esempi reali di mercato sono stati elencati in sezioni separate. Successivamente, lo stato di sviluppo di ciascun biomateriale è stato discusso da una prospettiva comparativa e con il supporto dei dati quantitativi relativi all'impronta ambientale dei biomateriali. Sono stati aggiunti brevetti, certificazioni e casi di studio rilevanti di aziende di bellezza sostenibile e upcycling per supportare la ricerca scientifica con applicazioni industriali reali. Infine, sono state brevemente discusse le opzioni e i materiali di confezionamento nel settore dei cosmetici per aumentare la sostenibilità complessiva dei prodotti.

Tutti i risultati della ricerca hanno sostenuto che i biomateriali sono molto utili nell'industria cosmetica e preferiti sia dai produttori che dai clienti. Essere biodegradabili, biocompatibili e avere un basso impatto ambientale e idrico sono i principali aspetti positivi che rendono i biomateriali appropriati nei prodotti di questo settore. Mentre i biomateriali di origine vegetale sono considerati più amichevoli per la maggior parte dei clienti, anche gli animali e altri bioorganismi sono comunemente utilizzati come fonti per i biocosmetici. I metodi di lavorazione utilizzati per ottenere ingredienti cosmetici dai biomateriali sono diversi e recentemente si stanno sviluppando tecnologie di lavorazione più sostenibili, che sono scarse di sostanze chimiche e solventi inorganici. Casi di studio e molti brevetti concessi elencati supportano i risultati della ricerca scientifica mostrando le reali applicazioni dei biomateriali nelle formulazioni cosmetiche. Per riassumere, questo studio combina conoscenze teoriche e casi reali di biomateriali nel settore cosmetico, con l'aiuto di revisioni comparative, dati sia quantitativi che qualitativi e una varietà di fonti. Ci sono diverse limitazioni in questo studio, ma è comunque una buona revisione completa dell'argomento rilevante che potrebbe aiutare come fonte per studi futuri.

Parole chiave: Biomateriali, materiali a base biologica, cosmetici, cura personale, materiali a base vegetale, materiali a base animale, stato di sviluppo dei biomateriali, LCA dei materiali a base biologica

EXECUTIVE SUMMARY

Introduction and the Purpose of the Thesis

Environmental deprivation, climate change, air and water pollution, uncontrollable waste, extinction of animals, and increasing health problems caused society to change their all basic habits to protect their future and surroundings. Due to these problems, products people use in their daily lives started to evolve into more advanced forms, including materials that are less impactful to their health, other living creatures, and the environment. Almost everyone in this world is in contact with at least one cosmetic or personal care product in their daily activities, therefore, they are exposed to all kinds of ingredients that are present in these products. Cosmetics and personal care products are types of products that contain several different types of synthetic chemicals that have profound negative effects on different systems in the human body (Mellowship, 2009). Thus, these product groups raise concerns in people's minds about the safety of ingredients. The shift in customer preferences in cosmetics and personal care products led to new developments in product formulation and the business models of the beauty industry. Several cosmetic brands are transforming their products including healthier and more sustainable material options such as bio-based materials to act towards their consumers' and society's concerns.

The purpose of this thesis is to deeply understand the biomaterial concept in the cosmetics and personal care industry and to prepare a compilatory review from academic resources present in the literature. A comprehensive literature review has been conducted by evaluating past research and experiments in the light of research questions. The detailed research findings have been supported by patents and certifications, real market examples, and case studies of specialized companies in the industry that are using biomaterials in their products. Each selected biomaterial has been examined by its development status in the cosmetic industry, with the evaluation of every aspect including aesthetic and mechanical properties, sustainability characteristics, origin, LCA, and environmental impact. Selected biomaterials have been examined comparatively depending on their carbon and water footprint, to better understand the logic of cosmetic sustainability as a whole. Finally, packaging materials for cosmetic products have been examined generically to understand sustainable packaging options in this industry. In addition to prepare a comprehensive review of the literature about bio-based materials in cosmetics field, this thesis also aims to define literature gaps to propose new areas of research in the future.

Literature about Biomaterials and Cosmetics Industry

Bio-based material, or biomaterial, can be defined as a material that is derived from living or once-living biological organisms or biomass that can be obtained both naturally and by processing (Curran, 2010). Biomaterials, as is mostly mentioned in this thesis, are increasingly used in various industries to obtain more sustainable business models across the world. Energy, construction, textile, electricity, food, pharmaceutical, medicine, packaging, cosmetics, and personal care industries are some of the industries where biomaterials are widely used as raw materials. Biomaterials have origins that are from biological creatures, such as plants, animals, and other micro or macro-organisms, therefore, they contain only natural compounds in the case where they are not processed by chemical substances. These biological origins of biomaterials make them free of hazardous synthetic ingredients that are commonly used in non-biologic materials in many industries including cosmetics and personal care. Thus, awareness and use are highly on the rise in almost all industries, including cosmetics and personal care, in terms of health, environmental, animal safety, and economic concerns (Singh et al., 2003).

Cosmetics and the personal care industry, or shortly mentioned as cosmetics only, are two of the big industries that are developing in a non-stop and increasing way, due to almost every individual including men, women, and even children continuously being in contact with at least one cosmetic product. The cosmetics industry provides its customers with a very wide range of products including make-up products, day and night face and body creams, oils and lotions, serums, hair and shower care products, nail polishes and nail care elements, lip care products, cleansers, tonics, sprays, hair dyes and many other types of products people use in their daily lives. Since almost everyone is in contact with these products, they are also in contact with all the substances these products have, which generally have harmful effects on health (Batinic et al., 2021).

While technology and social media becoming a key point of everyday life, they also increase society's awareness towards their health and the whole world. Increasing concerns about their health pushed people towards more innocent products including fewer chemicals and natural materials. In addition to their health concerns, increasing trends over animal wellbeing, climate change, natural resource scarcity, and many other concerns toward the environment change the desires, needs, and expectations of consumers towards the products they use. Cosmetics and personal care products are some of these industries that are affected significantly by these rising trends. Cosmetics being in contact directly with the human body, having several synthetic chemicals in products, and consisting of large amounts of unsustainable packaging material

made the industry target for many concerned people and activists. These movements led to a variety of changes in the cosmetics industry including the substitution of chemical materials with natural ones including biomaterials, more sustainable packaging materials and systems, more sustainable shipping procedures, and the elimination of animal testing.

The substitution of chemical materials with biomaterials is an increasing trend in the cosmetics industry. Biomaterials are highly preferred in cosmetic formulations due to many different reasons. First of all, biomaterials are biologically sourced products, which make them free of hazardous and toxic synthetic ingredients. Being bio-based also makes these materials highly biocompatible for the human body, making them less allergenic, hormone disruptive, cancerous, in summary, less harmful to the human systems compared to its chemical substitutes. Moreover, biomaterials are highly biodegradable and compostable, and cause very little or no impact on the environment at their disposal stage (Moreno-Camacho et al., 2019). On the other hand, biomaterials such as animals, plants, and food have been used as natural and traditional remedy sources for decades, which brought the trust of society towards these materials.

Biomaterials having a wide variety of benefits to the human skin is one of the main reasons why they are highly developed in the cosmetics industry. The cosmetics and personal care market is worth more than 500 billion dollars in 2023 and is expected to grow even more in the future (Statista, 2023). Natural, organic, bio-based, and eco-friendly cosmetics are the most desired and famous concepts present in the industry lately, therefore, sustainable cosmetics, which consist of different cosmetic trends such as bio-cosmetics, green, and organic cosmetics are gaining more importance because of the shifting preferences. The sustainable cosmetics market is already worth more than 50 billion dollars (Allied Market Research, 2022).

Customer perceptions towards biomaterials are vitally important for products with biomaterials to be successful, even though it's proven that these materials are better in terms of health and environment. Literature shows that a large group of consumers are in favor of using bio-based products instead of synthetic and harmful chemicals and they perceive bio-based cosmetics as eco-friendly, harmless, and sustainable (Sajincic et al., 2021). While most of consumers have positive thoughts towards biological materials, there are several confusions regarding the biomaterial concept. Biomaterials are commonly confused with organic and natural materials, which are different. This fact supports that awareness of the reality behind biomaterials can be improved. Moreover, for some customers, bio-based cosmetics are only limited to packaging. On the other hand, consumers who are concerned with animal wellbeing are mostly persistent in bio-based cosmetic products which include animal-based ingredients. Environmental

concern is still one of the biggest motivations of customers, pointing out the need to expose the environmental effects of biomaterials as much as health effects. In short, there are mixed thoughts and motivations in people's minds regarding biomaterials in the cosmetic industry, which makes this topic an area of interest (Sijtsema et al., 2016).

Research Methodology

In this research, cosmetics and personal care industries have been selected to be examined, due to biomaterials being highly developed and commonly used in these industries. A generic literature review has been conducted about the industry and the biomaterial use in this industry. The first section, introduction, consists of the synthesis of academic literature about the definition of biomaterial, cosmetics, and personal care market, customer expectations from cosmetic products, thoughts about natural and bio-based cosmetics, changing behavior towards products, bio-based concepts in the cosmetics market, and the most recent market and industry statistics. This introductory literature review of biomaterials and the cosmetics industry oriented the research design phase to study biomaterials from their different perspectives.

To understand the biomaterial concept in the cosmetics and personal care industry, representative materials have been selected to be examined in this study, then they have been grouped depending on their origins, which are plants, animals, and other biological organisms. The selection of materials has been done after detailed research on market and industry information in web sources. Materials that are being used very commonly in cosmetics and personal care products have been listed and these materials have been searched concurrently from academic resources to understand the extent of available sources. Finally, 19 materials have been selected as representatives to be examined in this thesis. Research questions have been defined as: "What are the role of biomaterials in cosmetics and personal care industry?", "What are the main advantages and disadvantages of using these materials?", "Which materials are more developed, effective and sustainable in the cosmetics field?" and "What are the real-life applications of biomaterials present in the cosmetics market?". These research questions have been used as guidance to conduct the comprehensive literature review for discovering all the aspects of biomaterials in the cosmetics and personal care industry. A comprehensive and compilatory literature research has been conducted in the Google Scholar database to answer the research questions. For each material, separate search queries have been conducted for each section including material summary, development status, patents, and examples. Also, the same database and search query method has been used for the packaging section. For case studies,

web sources and companies' websites have been used to explain their business models, products and biomaterial uses.

Research Findings section of this study consists of the answers to defined research questions obtained from the literature review. Research queries from Google Scholar have been conducted separately for each 19 biomaterials that have been chosen for this study. The research findings section consists of a detailed synthesis of each material including their functions, processing, advantages, disadvantages, and industry examples. These findings later have been supported by comparative development status analysis, patent study, and special case studies, which are the topics of the fourth, fifth, and sixth sections.

Research Findings

The first group of research findings which is Analysis of Biomaterials, comprises a detailed analysis of a specific material including information such as the benefits of that biomaterial for the skin, in which forms it is used in cosmetics, production and processing methods for cosmetic formulations, advantages and disadvantages, and the examples of products and beauty brands from the market to support the academic literature. While the main analysis of the biomaterials has been sourced by academic papers, industry data, blogs, news and websites of some cosmetic brands have been used as supportive sources in the product example parts. In this section, 19 biomaterials have been selected as exemplary to be discussed in this thesis. These materials are then divided into 3 groups depending on their origins: plants, animals, and other bioorganisms. The 12 of all these biomaterials belong to the plant-based group and are listed as aloe vera, banana, blueberry, cacao, citrus fruits, coconut, coffee, cucumber, eucalyptus, olive, pineapple, and tea. On the other hand, 5 of the biomaterials have origins in animals, and these biomaterials can be listed as chitin, honey, milk, silk, and snail slime. The final group of biomaterials consists of two elements which are algae and fungi that are classified under the name of other biological organisms. The analysis of the mentioned biomaterials showed that almost all of these materials have been used as antioxidant, antimicrobial, and healing agents in cosmetic products in common. Furthermore, all biomaterials are effective in overall skin protection, skin moisturizing, and skin cleansing, in addition to their other benefits that are specific to some materials. Biomaterials are mostly preferred for their special benefits such as acne healing, sun protection, oil balancing, and anti-aging, as a substitute for several chemical ingredients. While animal-based materials are mostly seen to be added to skin creams or lotions, plant-based biomaterials have been seen to be added into almost every type of cosmetics and care product ranging from make-up, shower, nail care, dyes, sprays, and oils. Past research regarding

consumer preferences also shows that due to concerns regarding animal safety, plant-based biomaterials are preferred over animal-based materials, and plant-based cosmetic products are perceived as more innocent, healthy, and sustainable. Processing methods and technologies differ depending on the biomaterial and product types they need to be added. While several green and mechanical methods can make all the processes sustainable, there are still many conventional methods in use that may require hazardous substances in the material extraction and formulation phases. Biomaterials have various advantages in terms of cosmetic applications. Common advantages of all the materials can be exemplified as their availability and biodegradability. Almost all plant-based biomaterials and some animal-based materials such as honey and milk are highly trusted and preferred products by society, which makes the application process of these materials into cosmetics easier. A vast amount of food waste is another advantage to take the opportunity for the cosmetic sector. Even though the advantages of biomaterials overshadow their disadvantages, processing some biomaterials may require time, effort, spending, and chemical substances that may create flaws in the overall sustainability of the biomaterial. On the other hand, relatively new materials such as silk and chitin require more research to increase the awareness and trust of the public as much as animal-based biomaterials. There have been diverse applications of biomaterials in the real cosmetics and personal care market recently, and these applications are continuously increasing. Many big and famous beauty brands such as L'Oréal, The Body Shop, Garnier, Neutrogena, Herbal Essences, Dove, and Sephora use a wide variety of plant-based biomaterials in their commonly purchased products. On the other side, specialized, sustainable, and high-end beauty brands such as MAC, Glow Recipe, Lush, Ole Henriksen, Clarins, Molton Brown, Mario Badescu, and many others use biomaterials in their products to provide healthier and more sustainable products for their customers. This information regarding beauty products and the market has been collected from both scientific and non-scientific blogs, news, and brand websites and connections between academic literature and market conditions have been made to explain how biomaterials are being adapted to our lives through cosmetic products. All these aspects have been summarized for each material separately, and at the end of the section, a detailed summary table has been created to show off the most important points of each analysis.

The Development Status of Biomaterials and Comparative Study section consists of the analysis to understand how each biomaterial is in the cosmetics field. This analysis has been conducted by defining criteria to evaluate the sustainability level of biomaterials, aesthetic characteristics, mechanical properties, and biological compounds to define how effective these materials are in

the cosmetics field. Evaluation criteria consist of the life cycle assessment tools and other sustainability scales which are: End-of-life cycle and recyclability, landfill, biodegradability, biocompatibility, renewability, compostability, and carbon and water footprint. These criteria have been defined from the findings of previously conducted literature review and they have been used to fill development status tables. For each biomaterial, a separate development status table has been formed and all information regarding the properties of a material has been registered. Development status tables contain information regarding the aesthetic properties of a material that defines its processability, origins of the material, availability of byproducts (type of byproducts), if a material is biodegradable, renewable, recyclable (and the type of recycling), compostable, etc. These tables also summarize the information obtained in the analysis of materials section, such as the forms that biomaterials used in products (extract, oil, water, etc.), processing methods used in the phase of cosmetic formulation, and other industries where that specific biomaterial is or can be used due to its properties. Furthermore, tables also include the names of supplier companies that are providing relevant biomaterials for cosmetic purposes. It has been seen from this section of tables that there are large cosmetic material supplier firms that are providing a wide range of biomaterials for cosmetic producers. To find these suppliers, a cosmetic material platform named "Special Chem" has been used for searching the suppliers of each biomaterial (© SpecialChem, 2023). Findings of all research and mentioned information about each biomaterial have been summarized in detail along with development status tables. After the explanation of the main findings, a comparative approach have been used in the final parts of each section to give comments on the comparative sustainability levels of materials by their carbon and water footprint numbers. Each material has been compared with others in a general perspective, to discuss which material may be more efficient to be used in cosmetic products, according to their carbon emission levels and water consumption. While this basic comparison is beneficial to give an idea about which biomaterial may be more effective for the overall sustainability of a cosmetic product, it is not right to say one biomaterial is more sustainable than another just because it has a lower carbon or water footprint. Development Status and Comparative Study section is important to understand how effective a biomaterial can be when applied to cosmetics or even other industry products. Additionally, examining the development status tables of all biomaterials altogether may foster the understanding of how each material differs from another and which can be more efficient or sustainable than the other. Moreover, this analysis is also a useful tool to evaluate these materials for other industry uses such as packaging or textiles.

The patents and certifications part includes the patents related to biomaterials and their uses in the cosmetics field. The main purpose of this section is to prove that findings from academic literature have been used by several scientists to realize the biomaterial used for their core benefits for the skin. Patents have been searched and collected from the Google Patents database and most related patents have been selected as exemplars, by using distinctive keywords and careful elimination steps. Research has been done separately and consecutively for each biomaterial, then results have been listed in different tables, including information regarding the patent number, name, country, the countries it is applied in, and short details of the inventions. In total, 219 patents have been listed for all 19 biomaterials. Patents have been selected from all over the world, from the year of 1985. However, it has been seen that most of the patents related to biomaterial-based cosmetics belong to Asian countries such as China and South Korea. Chosen patents include information such as the processing methods of material for cosmetic use and several different types of cosmetic formulations for cosmetic and personal care products. A big proportion of the patents chosen consisted of different cosmetic formulations that are based on the mentioned biomaterials in this thesis. Along with cosmetic formulations, there are different patents explaining how specific biomaterials should be processed to be added to cosmetic products. Additionally, general regulations toward human health, animal safety, environment, and anti-counterfeiting have been explained in the section and the most commonly granted certifications have been listed in this section. While formulating cosmetic products with biomaterials, it is important to follow regulations towards health and the environment, for example, the amount of chemical substances and metals in products, such as arsenic, mercury, or lead. On the other hand, many customers require products that are 100% nature-based, vegan, or 100% bio-based, which may lead to the need for trusted certifications such as COSMOS, ECOLABEL NATRUE and ICEA (Bozza et al., 2022). ICEA is also the responsible organization in Italy for the granting of cruelty-free certificates, including Leaping Bunny and PETA. Finally, there are diverse certifications, regulations, and systems to protect authenticity, which is important in the bio-based cosmetics sector, since the products belonging to that group are more scarce and expensive than standard conventional cosmetic products.

The Case Studies section includes examples from sustainable beauty brands that specialize in one or several biomaterials, biomaterial producers and suppliers in cosmetic sectors, and upcycling companies where cosmetic materials have been produced. In the selection phase of these companies, separate research has been carried out on the web for each biomaterial

mentioned in this thesis, however, there is information related to specialized brands only for some of these biomaterials. 3 companies have been selected as exemplary to represent specialized brands on particular materials, which are algae, banana, and chitin. These companies are named respectively as AlgAllure, Kadalys, and Primex. In addition to these specialized brands, larger-scale sustainable beauty brands that use biomaterials in their products have been searched in web sources and 5 more companies have been selected which are named 100% PURE, BYBI, LOLI Beauty, Nature in Bottle, and Provital. Finally, other groups of sustainable companies that carry out upcycling activities with food wastes and produce cosmetic materials have been studied and 3 representatives have been selected which are namely Kaffee Bueno, Upcircle Beauty, and Upcycled Beauty Company. All of these companies have been extensively examined from their websites and through web sources, then a detailed synthesis of each company has been prepared to show how they carry out their activities, which biomaterials they use in their products, what type of cosmetics and personal care products they are serving for their customers, what kind of processes they use, what type of certifications they have and what kind of other sustainable actions and projects follow. The purpose of this section is to show real-life examples from the sustainable beauty industry to prove the findings from the academic literature.

Finally, the packaging of biomaterials section includes an expletory study on sustainable packaging materials in the cosmetics industry, how bio-based materials can be applied to cosmetic packaging and what is the impact of sustainable packaging in the cosmetic and personal care industry. The packaging section is a complementary part of this thesis to show how bio-based cosmetic products can be supported with more sustainable packaging options and which of the relevant biomaterials or other sustainable materials can be used to increase the probability of products being successful in the market. In addition to the ingredients inside the beauty products, sustainability of the packaging is also very important for customers, especially for the ones who have concerns about the environment. Harms of plastic to all living creatures and the amount of non-degradable waste have emerged as serious problems recently, and plastic packaging is one of the main causes of this situation (Alabi et al., 2019). Instead of plastic, metal, glass, paper, and wood are some of the sustainable materials that are being used for cosmetic packaging (Bom et al., 2020). While glass and metal have the advantages of being highly recyclable and giving elite perceptions, paper and hemp are more advantageous in terms of biodegradability, low carbon footprint, being lightweight, and low cost. Hemp is another bio-based material that has been used as a sustainable packaging material recently. Being bio-based,

highly biodegradable, low-cost, and durable, it is increasingly being preferred as a material instead of plastics. Hemp can also be used to produce bioplastics, and this way, in the form of bottles or jars, it can be applied to cosmetic products (Promhuad et al., 2022). Some of the biomaterials discussed in this study are also used in the packaging industry. Bananas, citrus and pineapple peels, coffee and tea grounds or trees, silk, chitin, and fungi are used as sustainable raw biomaterials in different types of packaging production. These biomaterials can substitute plastic packaging materials, plus, they can also be used for bioplastic production, therefore these materials can be part of cosmetic products from both inside and outside.

Discussion and Conclusion

This thesis covers biomaterials topics in the cosmetics field, with a comprehensive academic resource review, industry examples, and case studies of selected representative biomaterials. Supportive quantitative data and comparative analysis have also been used to understand the sustainability concept in this field in a better way. This study aims to set up a useful groundwork for theoretical or practical future studies that may be conducted in the biomaterial-based cosmetics field. Another target of this thesis was to define the possible literature gaps and to realize the potential for improvements for future research in the relevant area. This study has some limitations including the extent of the resources used, lack of some quantitative data regarding sustainability scales, and non-scientific sources that have been used for case studies and industry/market examples. Overall, this thesis constitutes a well-rounded report including a detailed analysis of the most important biomaterials, their development status, industry examples, and comparative studies.

1. INTRODUCTION

1.1. Biomaterial Definition and Bio-based Materials

Changing climate, increased pollution, and skyrocketing health problems caused society to start considering their lifestyle and the way the products they use affect these issues. Even though the artificial substances used in everyday life provide many ease and benefits to people's lives, many harms are also accompanying these benefits. While in the past these problems were not considered vital, the amount of increasing environmental disasters and problems with wellbeing caused everyone to become more aware of the hazardous nature of chemical and artificial substances. At this point, bio-based materials and solutions become an important aspect. For these reasons, in the last decades, usage of the biomaterials instead of artificial materials has increased significantly, this fact is mostly because of the biocompatible, biodegradable, non-toxic, and non-allergenic nature of the biomaterials (Moreno-Camacho et al., 2019).

Biomaterials can be defined as a class of materials that are produced and rooted by living biological creatures and organisms such as plants, animals, humans, microorganisms, or other living forms. To set up a more general definition; biomaterials, which also be mentioned as bio-products or bio-based materials, are natural and organic kind of materials, chemicals, and energy that are obtained from biological sources or wastes from natural organisms, and that's the reason why biomaterials have also renewable and reusable features (Chandel et al., 2011). Biomaterials have started to be chosen as an ingredient in many products due to their vast availability in nature, being sustainable environmentally and economically since they are easily and naturally available, and help the practices of green production and consumption (Toker-Bayraktar et al., 2023).

Biomaterials can be in the form of living and lifeless creatures, or a combination of both. And they can include many different substances such as natural biopolymers, composites, ceramics, and metals in their formations (Dziuba et al., 2021). All these substances can be extracted with many different types of natural or chemical processes from different biological creatures such as plants, animals, fungi, bacteria, and other organisms. Most known and used biomaterials can be exemplified as algae, herbal oils, mycelium, plants, shells, bones, food wastes, and animal tissues. In addition to the extraction from living organisms, biomaterials can also be obtained by the many different types of processes of diverse biologic substances such as enzymes, biopolymers, bio-solvents, pigments, and other organic acids (Gutierrez-Macias, Hernandez De Jesus and Barragan-Huerta, 2017).

The importance of biomaterials is growing each day. One of the most important reasons for this increased awareness of biomaterials is their wide and diverse application in many fields such as medicine, pharmacy, fashion, cosmetics, etc. Thanks to their completely biological nature, they create many opportunities for new uses of materials, and more sustainable and healthier applications and methods. The use of biomaterials is getting more and more crucial in the era of raising environmental concerns and sustainability actions from the public and governments, in addition to the increasing health impacts of hazardous and non-biologic substitute materials used in many fields and products in everyday life of people (Singh et al., 2003).

The most frequently used biomaterials are generally rooted in plants, fruits, vegetables, their trees, wastes, and fluids. Most common examples for this case can be given as food wastes such as banana peel and orange peel, in addition to the leaves, branches, and water of these fruits and many others. In addition to banana and orange peels, apples, celery, carrots, spinach, and olives are other types of edible plants that are commonly used in many industries' products such as fashion and personal care industry. Especially in personal care and cosmetics area, fruit oils, water, and peels are used very commonly as biomaterials, since they are natural in addition to their many diverse benefits to the human skin and health (Toker-Bayraktar et al., 2023).

On the other hand, in addition to the plants, a large volume of non-eaten food waste creates an immense opportunity to produce biomaterials from this food waste, which is full of biological ingredients that can be used as materials in many different areas. According to Ryder et al., remarkable amounts of protein-based dairy products are produced each day and this issue causes a substantial amount of organic waste released into the environment, causing oxygen levels in the ecosystem to drop significantly. That waste full of healthy nutrients can be turned into the ingredients used in daily care products which can benefit in many aspects (Ryder et al., 2017).

Other sources for producing biomaterials are animal tissue and waste. In past research, it has been seen that animal skin, bones, feathers, and shells become natural and sustainable materials that have been used in different industries such as pharmaceuticals, cosmetics, medicine, textiles, food, ceramics, energy, tissue engineering, and polymer industries. According to previous research, waste derived from poultry, cattle, pigs, sheep, goats and many other animals creates a huge opportunity for biological substances that can be used in the production processes in many sectors (Tarafdar et al., 2021).

At that point, many companies certainly desire to follow their customers' needs and requirements and eventually search for more natural and sustainable materials and processes to apply to their products. That's why, the number of sustainable biomaterials used in cosmetics has increased drastically recently. Many producers switch to materials from biological sources from plants, animals, and other microorganisms to create healthier, more sustainable, economical, and cleaner products and services (Wang et al., 2014). In addition to satisfying their customers' needs and increasing their share and profits, many brands also desire to support the environment and sustainability in many terms for a better future for the world. Moreover, governments from many different countries are continuously releasing incentives and rules towards companies to support sustainability and adopt more environmentally conscious practices (Almeida et al., 2021).

1.2. Cosmetics and Personal Care Market

Cosmetics and personal care products have enormous growth in the market since almost everyone is in touch with at least one care product in their daily life. According to the data, the current market size is around 500 billion USD and is expected to increase more in the following years (Statista, 2023). On the other hand, market needs are changing towards green and bio-based products and this change cause the sustainable, natural, and organic cosmetics market to grow. Various large and known cosmetics brands are now replacing the materials they use in their products, shifting to more sustainable processes, and changing their marketing structure to attract concerned customers (Bozza et al., 2022). According to reports, the global sustainable cosmetics and personal care market size has grown to more than 50 billion USD in 2021 and is expected to reach 130 billion USD by 2031 (Allied Market Research, 2022). In summary, the rising awareness and need for bio-based products led to an increase in the importance of bio-based materials and substances in cosmetics and personal care products.

1.3. Concerns of Consumers and Need for Bio-based Cosmetics

The skin is one of the most important and the largest organs of the human body which protects it from many outside effects. Since it has the utmost importance for living creatures, the protection and well-being of the skin is vital. For the last decades, chemical substance usage in skin care products has increased dramatically, eventually causing the increase of many problems in skin tissue such as irritation, sensitivity, allergic reactions, and more (Coltelli and Danti, 2020). Additionally, it is found that the use of these substances also leads to the decreased performance of skin to regenerate and heal itself. All of these issues raise the consciousness of

both skin care product users and producers, making them more aware of the importance of using more biomaterials on the products to protect the skin in a better way (Singh et al., 2003).

In recent years, customers are getting more sensitive about the products they use on their skin, especially about the chemicals inside these products. Increasing media coverage about the unhealthy effects of chemical substances in personal care and cosmetic products makes people shift from more natural-ingredient products. In addition to that, thanks to social media and environment-conscious platforms, customers are shifting more towards more environmentally friendly products rather than carelessly using products with highly artificial and chemical-loaded products (Wang et al., 2014).

Current sustainability trends and movements, increasing ecological problems, and the use of social media have significantly impacted and changed the thoughts of customers on the products they use daily. The awareness of the hazardous chemicals and the consequences on health and the environment of using them shifted customers' needs dramatically to bio-based products which are both eco-friendly and healthy. While there are mixed opinions about biological product-based cosmetic products in terms of ethics, prices, and trustworthiness, the demand for bio-based cosmetics is increasing rapidly. This is mostly due to customers' desire to decrease their carbon footprint and protect themselves from the health issues that chemicals can cause (Suphasomboon and Vassanadumrongdee, 2022).

1.4. Customer Perceptions Towards Bio-based Cosmetic Products

As a general view, customers are confused about the definition of bio-cosmetics. In the literature, bio-based cosmetics are often mentioned as Biocosmetics, Green Cosmetics, Natural Cosmetics, and Organic Cosmetics. When asked to the customers what they know about bio-based cosmetics, answers differentiated such as products being cruelty-free, plant-based, recyclable, non-chemical, and more. So, it is clear that there is confusion in customers' minds about bio-based products (Sijtsema et al., 2016). In real, biocosmetics can be defined as hair, skin, body care, and makeup products that have 100% natural ingredients derived from plants and fruit extracts, food waste, animals, and other microorganisms. While 100% of bio-based products are barely non-existent in the market, bio-chemicals and bio-compounds-containing products are also considered bio-based products. (Goyal and Jerold, 2023).

Customer perceptions about bio-based cosmetics vary depending on the type of product and the brands. While deciding to purchase a product, customers mainly check the price of the product, the brand, the source of the biological ingredients, and the certifications of being eco or green.

Additionally, the main motivations of the consumers purchasing bio-based cosmetic products are biodegradability, recycling capacity, and reusable packaging. The surveys conducted in the research show that the term bio-based is not very appalling to customers as sustainable, biodegradable, and eco-friendly cosmetics (Gaffey et al., 2021).

Another research shows that three types of customers are willing to purchase green cosmetics products and they are listed as 'health-conscious customers', 'environmentalists', and 'quality hunters'. The main criteria of purchase decisions of these groups of customers vary between quality, environmental-friendliness, animal welfare, and health benefits. In addition to these main motivations, the same research also claims that for younger customers, the price of these sustainable products is also significantly important along with the certifications and ingredients. The confusion about sustainable cosmetics is obvious. Even though animal-based materials are included inside biomaterials, many customers do not accept that fact and claim they do not purchase products that have materials extracted from animal tissues. Many participants in the research also explain that they think bio-based cosmetics are mostly about individual health and are not effective on the environment at all (Cervellon and Carey, 2011).

To summarize, it is seen that the reasons why consumers desire to purchase bio-based cosmetics differ depending on their biggest concerns. While bio-based cosmetics are commonly defined as cosmetics containing bio-materials, many people perceive this term differently. Nevertheless, customers in general have positive thoughts about biomaterials, especially plant and fruit-based materials. Biomaterials obtained from animals and other microorganisms are still questioned by some groups. In the end, biomaterials in cosmetics and personal care products have become vitally important recently since demand from the green, organic, and sustainable cosmetics market is increasing continuously.

2. RESEARCH METHODOLOGY

The main aim of this research is to synthesize and summarize the most commonly used biomaterials in the cosmetics and personal care industry by studying various aspects of biomaterials including their uses, benefits, forms, and processing methods. A comprehensive and compilatory literature review has been conducted in this thesis to understand all the facts related to the use of different biomaterials in the cosmetics and personal care industry, including their use areas in that particular industry, their processing methods, advantages and disadvantages of using this material, development status of biomaterials in different areas, and patents and certifications related to the materials cosmetic formulations, processing, and application. After conducting an introductory literature review regarding the biomaterials and cosmetics market, research questions have been design to explore the relevant topic from almost all perspectives. 4 research questions can be listed as:

RQ1: ‘’What are the role of biomaterials in cosmetics and personal care industry?’’

RQ2: ‘’What are the main advantages and disadvantages of using these materials?’’

RQ3: ‘’Which materials are more developed, effective and sustainable in the cosmetics field?’’

RQ4: ‘’What are the real-life applications of biomaterials present in the cosmetics market?’’

Google Scholar platform has been used as a primary database to obtain relevant past research since it is one of the platforms that has the most various and vast academic sources including journals, books, conference papers, and scientific websites. The initial search has been conducted to understand the ‘biomaterial’ concept in the cosmetics field and the selection of biomaterials to be included in this study. Search keywords have been selected as ‘biomaterials in cosmetics industry’ and ‘bio-based materials in cosmetic and personal care industry’, then, abstracts and keywords of several articles have been evaluated to see which materials have mostly been mentioned in past research in the relevant field. Additionally, an informal search on the web was also conducted to see which bio-based materials are being used in cosmetics and personal care products in markets recently. These informal research findings from web sources were then followed by academic research in Google Scholar, to demonstrate if the real-life use of biomaterials has a proven scientific basis. Initial research was concluded with the selection of 19 different biomaterials that are most commonly used in beauty products, which also have many scientific research and experiments have been done on them in the past. These

materials then have been separated into 3 groups depending on their origins, which are plants, animals, and other biological organisms, which can also be seen as a list in Figure 1.

BIOMATERIALS		
Plant-based	***Animal-based***	***Other Bioorganisms***
● Aloe Vera	● Chitin	● Algae
● Banana	● Honey	● Fungi
● Blueberry	● Milk	
● Cacao	● Silk	
● Citrus Fruits	● Snail Slime	
● Coconut		
● Coffee		
● Cucumber		
● Eucalyptus		
● Olive		
● Pineapple		
● Tea		

Figure 1: Biomaterials Grouped by Their Origins

The first section of this study consists of a comprehensive review of past research regarding all biomaterials selected in the field of cosmetics and personal care. For each material, a separate search query has been done in the Google Scholar database, and properties of a specific biomaterial, its benefits in the cosmetics field, processing methods and technologies, and advantages and disadvantages have been provided with details to deeply understand that material. Search queries were conducted by using the keywords of the ‘’name of the material’’ (i.e. ‘’banana’’, ‘’coffee’’, ‘’silk’’, etc.), ‘’cosmetic use’’, ‘’cosmetic applications’’ and/or ‘’in skin care’’ to find most relevant articles. After the manual reading and control of all the articles collected by keyword research, the most relevant articles have been kept to be used in the findings sections. For each biomaterial, 15-20 sources have been selected and listed to be examined. Additionally, examples from markets including big and known beauty brands, smaller brands that specialize in sustainable cosmetics or a specific material, and bio-based material suppliers have been given to prove the real-life use of bio-based materials in the industry. These sources have been taken from websites of the brands, cosmetics, and sustainability blogs and news.

The development status of materials and KPI section includes information about the main characteristics and sustainability level of biomaterials. Development status tables have been formed for each material separately, and include information regarding the origin of the material aesthetic characteristics, end-of-life behavior, and environmental impact of producing and disposal of that particular material, including its carbon and water footprint. This information has been collected by several different sources including academic journals and scientific websites retrieved from the Google Scholar database. Additionally, material databases and sustainability blogs have been used to obtain the names of supplier companies and numbers regarding the carbon and water footprint of the biomaterials. To collect information regarding the other industry uses of biomaterials (textile, packaging, accessories, etc.), extensive searches have been done in web search engines, and news, blogs, and websites of startup companies have been used as a source to connect academic literature findings with real industry applications. Comparative clauses have been used to evaluate materials in terms of their carbon and water footprint. Each material has been compared with other materials in its origin group (i.e. tea is compared with other plant-based materials), and other groups (i.e. a plant-based biomaterial versus animal-based biomaterials). These comparative methods have been used to have a general idea about whether one group of materials is more efficient than another (i.e. plant-based vs animal-based), and which specific materials are less impactful.

In the patents and certifications section, various patents have been studied separately for each material to see how they are used, and processed and how developed is that specific material in the cosmetics field. Google Patents platform is used to find patents related to each material by using keywords including material name (e.g. ‘banana’, ‘chitin’, ‘citrus’), ‘extract’ and ‘cosmetics’, ‘skincare’, and ‘haircare’. For some of the materials such as fruits, ‘oil’ and ‘water’ extensions are also added since these forms of fruits are commonly used in cosmetics and personal care products. Patent research has been conducted separately for each biomaterial and each query resulted in more than 1000 results. Elimination is done for patents that do not contain the ‘biomaterial’ and ‘cosmetic’ keywords together. Additionally, patents with cosmetic formulations that do not use the particular biomaterial as one of the main ingredients have also been eliminated. So, only biomaterials which are one of the main ingredients in cosmetic formulations have been considered. After that point, the manual selection was done by reading the abstracts and ingredient lists in cosmetic formulation patents, and then similar formulations, processing methods, and duplicates (different versions of the same patent such as country,

language, etc.) were eliminated. In the end, 219 patents have been selected in total for all biomaterials to form the patent lists, which can be seen in Figure 2.

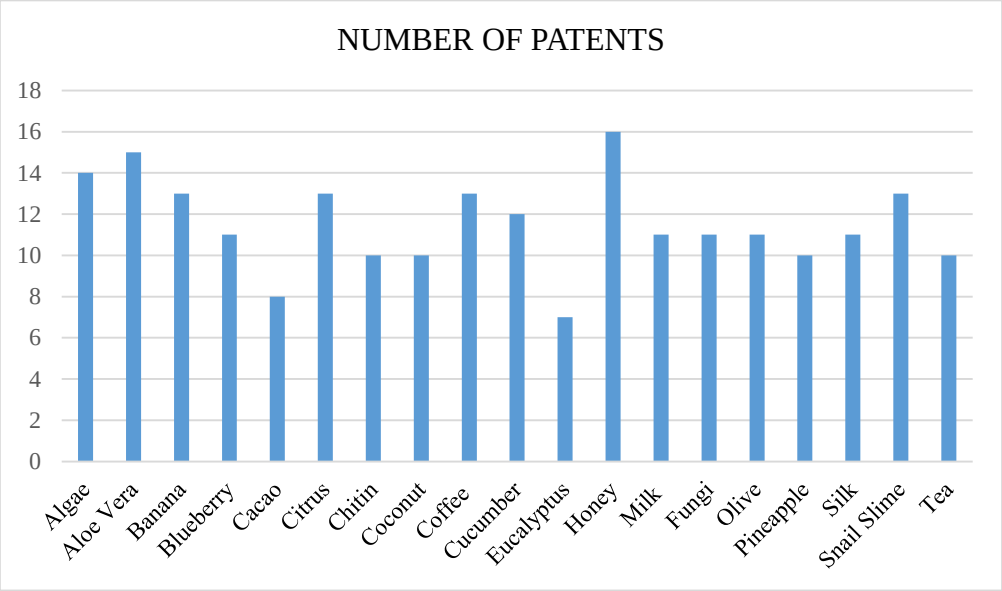

Figure 2: Patents Listed for Each Biomaterial

Patent tables have been created separately for each material and include information such as patent number, patent name, publication year, issuing country, countries where the patent is in use, and some details about the patent. While most of them belong to Asian countries such as China and South Korea, there are several patents published by different countries such as the USA, Canada, France, and others. The table below shows in which continents and countries the patents originated (Figures 3 and 4). It can be seen that a significant amount of the patents belong to Asian countries, which is then followed by America and Europe.

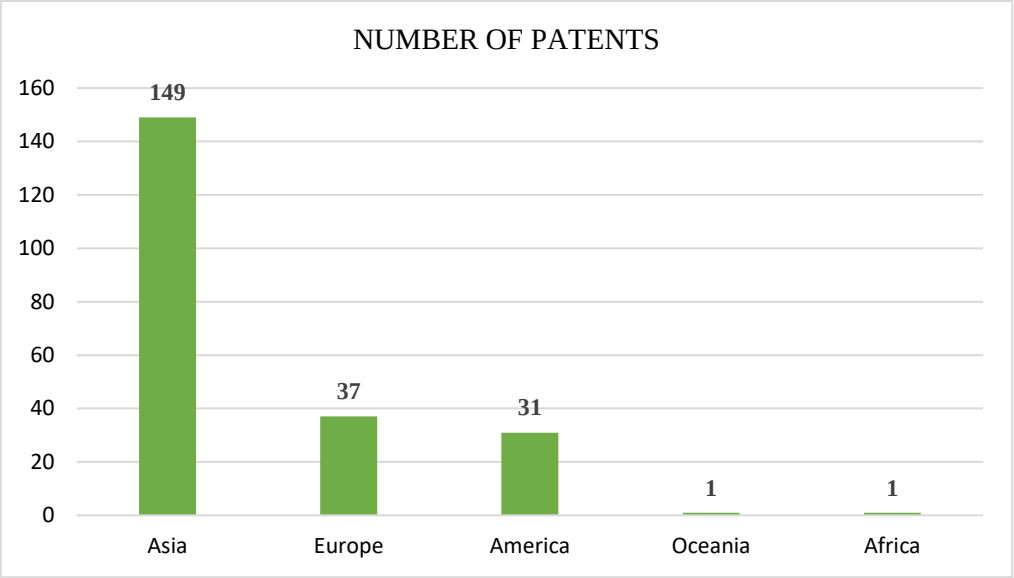

Figure 3: Patents Distribution by Continents

South Korea	China	USA	France	Japan	Germany	Spain
86	50	27	22	9	4	3
Australia	**Brazil**	**Switzerland**	**Russia**	**Canada**	**Bulgaria**	**Mexico**
2	2	2	1	1	1	1
Romania	**Iceland**	**Netherlands**	**Thailand**	**Taiwan**	**Great Britain**	**Cameroon**
1	1	1	1	1	1	1

Figure 4: Patents Distribution by Countries

Patent selection has been limited by publication dates between 1985 and 2022. The distribution among the years of publication can be seen in Figure 5.

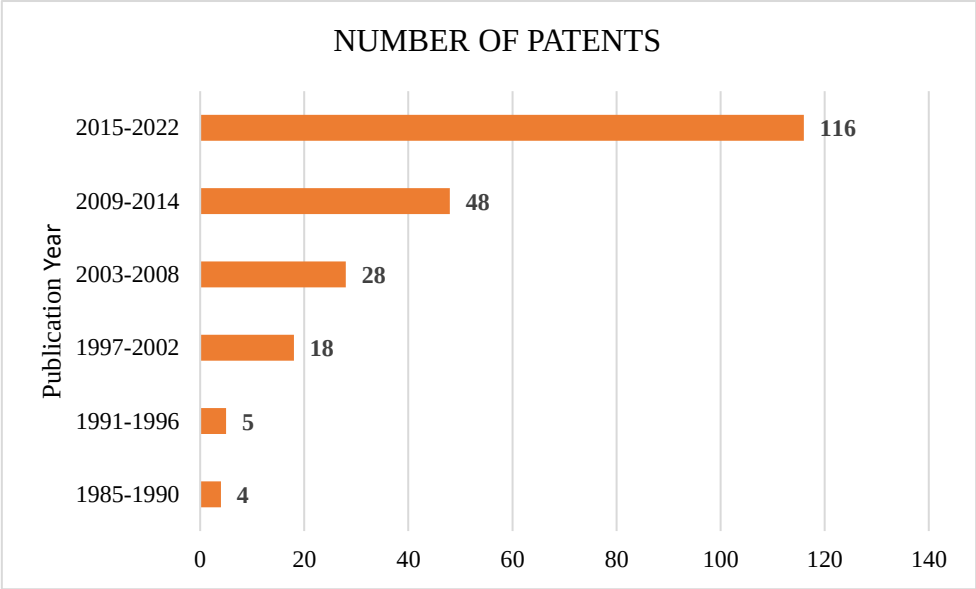

Figure 5: Patents Distribution by Publication Year

The case study section presents examples of specialized sustainable beauty brands that use the biomaterials that are mentioned and discussed in this thesis. Selection of companies and beauty brands are conducted by research on the web by using biomaterials names as a keyword along with ‘bio-cosmetics’, ‘biotechnology’, ‘startup’, and ‘brand’. An example research wording included queries such as: ‘coffee-based cosmetic company’, ‘bio-based cosmetic brands’, ‘algae cosmetic’, etc. Several companies gathered by these researches and manually evaluated if they have a solid customer base, sustainable materials use, and processes and relevant to this study. Separate research is conducted for each biomaterial mentioned in this thesis, however, on the web, there is information related to specialized brands only for some of these biomaterials. 3 companies have been selected as exemplary to represent specialized brands on particular materials, which are algae, banana, and chitin. In addition to the brands that are specialized in one or a couple of biomaterials, larger brands use several different bio-based materials that are mentioned or not mentioned in this thesis by using keywords ‘sustainable cosmetic brands’, ‘bio-based cosmetic brands’, and ‘natural cosmetics’. Manual evaluation of each website has been screened manually to determine if it uses the biomaterials and processing methods relevant to this study. Along with these criteria, 5 companies have been selected. Finally, companies that specialize in upcycling food waste to produce cosmetic materials and products have been searched by using ‘upcycling cosmetics’, ‘upcycling food waste’, and ‘upcycling fruit waste’ keywords. 3 brands with the most relevant materials and actions have been selected as exemplary in the case study part.

In the packaging section, first of all, sustainable packaging materials that are used in cosmetic products have been searched in Google Scholar with the keywords ‘sustainable packaging materials’, ‘cosmetic packaging’, and ‘bio-based packaging in cosmetics’. This expletory research gave several articles with the preferred sustainable materials that are used in cosmetic packages, including glass, paper, metal, and wood. From this general research query, the 3 most relevant papers have been selected to summarize these sustainable packaging materials with their use, advantages, and disadvantages in the cosmetic context. Finally, hemp packaging, which is a new area of research, is a bio-based sustainable packaging method that has been evaluated for cosmetic use. Relevant sources for hemp packaging have been obtained from academic papers in Google Scholar, which is scarce, and startup companies that are conducting the production of hemp packaging.

3. RESEARCH FINDINGS

3.1. Biomaterials in the Cosmetic and Personal Care Industry

Increasing awareness and consciousness of consumers towards health, environment, and social issues encourage cosmetics and personal care brands to develop product formulations including more sustainable materials and processes. With the help of the abundancy and availability of the different types of biological creatures, plants, and waste present in nature, more biodegradable, compostable, and biocompatible materials increasingly taking the place of synthetic, chemical, and other hazardous ingredients in cosmetics and personal care products. Biomaterials that are being used in cosmetics and personal care products are vast and various, which mostly consist of plants, animals, biologic waste, and other micro or macro-organisms.

In this section 19 different biomaterials have been selected and divided into groups depending on their origins such as plant, animal, and other micro/macro organism-based materials. These materials have been specifically selected after overall research in internet sources and academic literature about which plant, animal, and other organism-based biomaterials are most commonly used as cosmetic ingredients. Then, these materials have been evaluated in detail regarding their benefits to the skin, how they are used in cosmetics and care fields, how they are processed for cosmetic use, their advantages and disadvantages in this field, and names of some companies that are using these biomaterials or suppliers have been given as examples to increase the realization towards these sustainable brands and companies. A detailed summary table can be seen in the Appendix 1 (Table 39).

3.1.1. Plant-Based Biomaterials in Cosmetic Products

3.1.1.1. Aloe Vera

3.1.1.1.1. Aloe Vera Plant in Cosmetics Field

Aloe vera is a plant that is grown in wild and tropical climates and used as a decorative plant or mostly, in the form of gels, creams, or other types of body products. Aloe vera naturally contains and produces a polysaccharide acemannan-based gel which is full of health benefits, therefore aloe vera has been used for centuries as a medical treatment agent for many conditions. While the oral consumption of this aloe vera gel is known to be dangerous and toxic, its topical application to the skin is found to be safe, except for some people who are allergic to the substances of the plant (Liu et al., 2019). Aloe vera contains almost all type of fundamental vitamins and minerals, several antioxidants, and other valuable organic phenolic compounds

which is vital for skin and overall health (Chandran et al., 2022). These facts make aloe vera a very convenient biomaterial that can be used as a natural source in cosmetics and personal care, substituting the needed chemical substances for healing skin-related problems.

As mentioned, the aloe vera plant has various significant benefits to the skin and other medical conditions. Aloe vera is one of the most used plant-based biomaterials in the wide category of cosmetics and personal care products, which can be listed as make-up bases, lipsticks and balms, body and face creams, sun lotions, cleansers, perfumes, after-shave lotions, and shower gels/shampoos. This wide and convenient use of aloe vera is thanks to the plant being both anti-bacterial, antifungal, anti-cancer, anti-inflammatory, antiviral, and antioxidant (Sharma et al., 2014).

First of all, aloe vera is a very effective moisturizer, which is used commonly on the body, face creams, and hair products. It's supportive of balancing the skin sebum, smoothening, and removing dead skin cells while hydrating the skin (Gupta and Rawat, 2017). That's the reason why it is also commonly used in skin cleansers and masks. Another proven benefit of aloe vera is the ability to protect the skin from UV lights and sunburns, and wound healing and refreshment of the skin in case of sunburns and other skin damages such as irritations or allergies (Dal'Belo et al., 2006). For this reason, aloe vera use in sunscreens, tanning oils, and after-sun care products is wide and appropriate, along with the after-shave lotions to refresh the skin and heal the cuts. The refreshment effect of aloe vera is also one of the reasons that it is included in dental care products such as toothpaste (Eshun and He, 2004). Moreover, it is also proven that aloe vera extracts prevent skin aging and wrinkling, with the help of the synthesis of collagen that aloe is capable of (Qadir, 2009). Several researchers also found out that aloe vera has anti-acne effects and reduces the imperfections on the skin, due to its rich nature of antimicrobial, antioxidant, and antibacterial compounds (Zhong et al., 2021; Rajeshwari et al., 2012). Thus, aloe vera is included in different types of facial products that claim to fight acne, excessive sebum, and imperfections.

Besides from skin care products, aloe vera is also used in hair care and shower products. While for shower products it is more about the freshness and smoothening effect is considered. For hair care products, aloe vera also supports hair growth along with moisturizing and sun protection properties. Aloe vera protects the health of the scalp, and stimulates hair growth, with the help of an emodin substance that boosts hair follicles (Shahi, Mehrizi, and Hadizadeh, 2017).

3.1.1.1.2. Production and Processing of Aloe Vera

Aloe vera extracts in cosmetics and personal care products are mainly obtained from the gel that is found on the leaves of the plant. Getting the gel from the leaves of aloe vera requires different kinds of processes depending on the area of use. The processes to get the gel can be listed as grinding, crushing, and pressing of the leaf, which are physical and traditional methods, which in general can be named traditional hand-filleted processing. This method is considered to be the most environmentally friendly processing method since all the steps are mechanical. On the other hand, there are two other methods including extra processing such as filtration, heat treatment, flash cooling, pasteurization, creating enzymatic reactions, and stabilization. These methods are named whole leaf aloe vera processing and total processing, which are differentiated by the used area of the plant. The processes to be implemented on the plant should be selected carefully since inappropriate methods of gel extraction may cause the loss of beneficial bioactive compounds (Ramachandra and Rao, 2008; Chandegara and Varshney, 2013).

3.1.1.1.3. Pros and Cons of Aloe Vera in Cosmetics

Aloe vera is a natural and biodegradable source that has been used for hundreds of years as a beauty ingredient. It is a very functional plant since it can heal many conditions at the same time, both in terms of skincare and internal medical problems. Also, after the use of the plant as a decorative plant, aloe vera leaves become a waste that can be valorized with upcycling, and valuable extracts from these leaves can be used as cosmetic ingredients (Sánchez et al., 2020). As mentioned in the section above, compared to several other biomaterials' processing phases, aloe vera has several processing methods that are considered green and both environmentally and economically sustainable. In short, aloe vera is a plant whose waste is very valuable, and active bio-compounds of these wastes can be obtained with methods which considered green. The very long history of the use of the plant also makes customers feel safe about the plant and attracts them along with its biological nature.

Even though aloe vera use has been common for a long time both as a traditional in-home and as a cosmetic ingredient, there are several cases of allergic reactions and toxicities have been reported in the past, especially in conditions where there are serious wounds on the skin, or the allergic skins (Maan et al., 2018). Another disadvantage can be mentioned as the requirement of intense labor and workload on green processing methods of aloe vera, which in the end may cause cost issues (Ramachandra and Rao, 2008)

3.1.1.1.4. Companies Producing and Using Aloe Vera

There are many aloe vera and aloe vera extract producers in the world. Many of these companies produce gels to be used in different kinds of products including both cosmetics and beverage industries. The names of the companies that produce aloe vera and its byproducts can be listed as Forever Living.com, L.L.C., Aloecorp, Inc., Aloe Laboratories, Inc., Aloe Vera of Australia Pty Ltd., Herbalife International, Inc., Lily of the Desert, Terry Laboratories Inc., Pharmachem Laboratories Inc., and many more (Basu, 2022; Expert Market Research, 2022).

Other than aloe vera producers, there are several brands specializing in natural cosmetics that are marketing various kinds of aloe vera-based products. Aloe Vera Cosmetics is an Australian brand that sells aloe vera gels, aloe vera-infused beverages, and aloe vera-based cosmetics and personal care products including anti-aging creams and balms, anti-acne products, scrubs, moisturizers, make-up products, fragrances, shampoos, and conditioners (Aloe Vera Cosmetics, 2023). Dr. Organic is a UK-based brand that sells organic cosmetics from various plant-based biomaterials including aloe vera. Their aloe vera-infused products range from toothpaste, dental washes, lip balms, body butter, and hair care products (Dr. Organic, © Big Green Smile Ltd, 2023). Pharmas Natur is another company, based in Germany, that serves aloe vera including care products ranging from day and night creams, lip balms, toners, body lotions, and after-sun care creams (Pharmas Natur, 2023). RAWW Cosmetics is another cosmetics brand that sells products with natural ingredients. The brand has many different types of nail polishes which have aloe vera extracts in them. Other than nail polishes, the brand also has aloe vera-infused foundations, mists, primers, hydrating serums, and creams (© RAWW Cosmetics, 2023). In addition to these specialized brands bigger brands such as Sephora, Dove, Kiehl's, SkinCeuticals, Mario Badescu, Humphreys, Vacation, Kinlo, Seven Minerals, and many others sell aloe vera-based personal care products, most are sunscreens and after-sun care products (Prinzivalli, Trakoshis and Hussein, 2023).

3.1.1.2. Banana

3.1.1.2.1. Banana Plant in Cosmetics Field

Fruit consumption in the world has been increasing remarkably in recent years. This fact is mainly because of the nutritional benefits the fruits have and the raised awareness of healthy eating. Banana is one of the most nutritional and loved fruits in this group. While banana is very commonly harvested and consumed, the amount of byproducts and waste from the consumption or food production is significant, eventually causing an increase in biological

waste, which emerges as a serious issue in the context of environmental sustainability (Vu, Scarlett and Vuong, 2018). Hence, banana byproducts and waste become a point of interest recently as a bio-based material for different industries, also because byproducts such as banana peels and leaves are rich in beneficial bio-active compounds (Avram, Gatea and Vamanu, 2022).

Numerous different researches have been conducted on banana fruit in the past, to define how it can be transformed as a biomaterial that can be used in different products. First of all, it is widely known that banana has moisturizing effects on the skin. That is the reason why skin care products include banana extracts inside their cosmetic formulations. Additionally, it has been found in previous research that banana peel is effective in healing wounds and preventing dryness of skin, owing to its wound healing and moisturizing capabilities (Rathinamoorthy, 2021). Thus, banana use in moisturizers, body and face lotions, and creams is appropriate, especially in the case of producing nature-based products.

In the literature, few researchers are claiming that banana fruit and peel extracts can be effective in acne healing and preventing acne formulation, due to the antimicrobial and anti-inflammatory bio-active compounds that banana extract has. Therefore, banana extracts obtained from fruit or byproducts can be applied to anti-acne care formulations as biomaterials. However, research on the banana use as acne treatment is few in number and further research and experiments are suggested for this topic (Madhan and Krishnaveni, 2016; Savitri et al., 2022).

Along with hydration and moisturizing effects, banana is also beneficial in terms of skin barrier protection. According to some past research, banana peels have antioxidant, UV protection, and anti-inflammatory effects on health, which supports the use of bananas for skin protection against sunlight or other hazardous incidents. Furthermore, according to several experiments conducted on banana peels, it has been found that bio-active compounds of peel extracts has also effects on healing wrinkles, and therefore it is a good agent for anti-aging products. (Vu, Scarlett and Vuong, 2018). In addition to the banana peel extracts, bio-active compounds extracted from banana leaves have also been found effective in preventing wrinkle formations, therefore supporting that banana-based cosmetic formulations are appropriate in anti-aging products (Yoo et al., 2016).

Banana use in hair care products is also very widespread. For decades, banana has been used as an ingredient in traditional hair care routines. This long-lasting use was due to the many benefits

that banana provides to the health of hair. Banana is full of fundamental vitamins, minerals, and potassium, which help hair to maintain its strength, stimulate hair growth, decrease fallouts, soften the hair tissue, and control dandruff conditions (Kumar et al., 2012). These are the main reasons why banana extracts are highly present in the formulations of shampoo, hair masks, repairing oils, and conditioners.

3.1.1.2.2. Production and Processing Methods of Banana

Banana extracts can be obtained from the fruit itself, peels, or leaves. Banana peels and leaves are mostly processed into banana powders to be used in the products that are produced in the pharmaceutical, food, and care industries. Banana peel powder is obtained after the processes of drying and grinding the banana skin after the consumption of the fruit. Then, extraction of the dried powder releases crude extract, fractions, and free bio-active compounds to be used as natural antioxidants and preservatives for wound healing and nutrition in various products (Vu, Scarlett, and Vuong, 2018). To benefit from the antimicrobial, antioxidant, and phenolic properties of the banana, these extractions should be carried out depending on the area of the material to be used. The most common and preferred extraction methods for banana can be listed as hot water extraction, microwave-assisted extraction, ultrasound-assisted extraction, BPE extraction, ethanol extraction, creating vinegar from the peel, producing flour and starch from the peel, or leaving it as powder alone, or using other organic solvents. (Manzoor and Ahmad, 2021; Putra et al., 2022). These methods include both mechanical processing and chemical solvents, so the sustainability of banana cosmetic material production may change with the method used.

3.1.1.2.3. Pros and Cons of Using Banana in Cosmetics

Using banana peels as biomaterials and bioplastics has different advantages and disadvantages depending on the way and products they are used. First of all, banana is consumed in huge amounts, which is why the fruit itself, waste, and byproducts are highly available. Banana has been used for past decades as a natural and traditional beauty routine, that’s why it is a biomaterial that is trusted by society and most people have positive behavior towards banana. Plus, the environmental impact of banana production and processing is low in terms of carbon and water footprint, which is another point proving that banana is a sustainable biomaterial (Mercereau, n.d.). Some of the processes needed to obtain cosmetic biomaterial from bananas may require time, cost, and synthetic or chemical solvent, which may decrease the sustainability level of all processes as a whole, but there are greener and more mechanical processes are also

available, as mentioned in the previous section. In the cosmetics field, even though the amount of banana waste is significant, fruit is preferred to be used in cosmetic formulations more than waste such as peels. Research to understand if the banana peel provides the same effects as fruit is limited. Since banana fruit is more attractive compared to its peel, banana peel is not applied to the products in a wide range, which may be a loss of opportunity. Therefore, more research proving the benefits of banana peel extractions in cosmetics may be needed to valorize the fruit in a better way.

3.1.1.2.4. Companies Producing and Using Banana

MakingCosmetics is a large cosmetic material producer company that provides many different types of biological and synthetic cosmetic materials. One of the materials they provide is banana extract which is obtained by extracting from parts of banana trees. This banana-based biomaterial is applicable for shower products, creams, serums, and other cosmetic materials that contain water (© MakingCosmetics Inc., 2023). Nature In Bottle is another company that produces natural and bio-based cosmetic ingredients which mostly consist of oils. This company has banana-based oils which can be sold to companies that require banana extract in their cosmetic formulations. Banana-based cosmetic materials they provide are listed as Banana Extract Oil, Banana Peel Oil, Banana Seed Oil, Banana Infused Oil, and Musa Paradisiaca Oil (© Nature In Bottle, 2023).

Kadalys, based in Martinique, is a personal care brand that uses thrown-out bananas and the leaves from banana trees inside their product formulations, to take nourishing and healing benefits of the banana as a whole, also following their responsible action to the environment and take the opportunity of waste food. The brand uses many different types of bananas, sometimes only the fruit, sometimes in a whole, and adds them to their creams, gels, and scents, targeting to obtain a sustainable, biological, and non-hazardous product that can be used comfortably by consumers while helping to decrease waste and green gas emissions (© Kadalys US, 2023). In addition to specialized and sustainability-focused smaller firms, various famous cosmetics and personal care brands such as The Body Shop, Lush, Sephora, Ole Henriksen, SkinFood, TonyMoly, Boots, Glow Recipe, Lanolips, Drunk Elephant and many others use banana extracts in their products ranging from creams, shampoos, shower gels, lip balms, masks, and cleansers to the mists (Fargo, 2021; Wirt, 2018).

3.1.1.3. Blueberry

3.1.1.3.1. Blueberry Plant in Cosmetics Field

Blueberry is one kind of berry that is increasingly planted and consumed by many people. Blueberry is preferred by millions and becoming very famous each day due to the high economic and nutritional value it carries. Blueberry is also mentioned as ‘’one of the five human healthy foods’’ due to its significant health benefits and the very rich nature full of antioxidants, anthocyanins, and phenolic acids, along with several other vitamins, minerals, and organic acids (Dermengiu et al., 2022). Blueberry is generally consumed as the fruit itself and as feedstock. Besides that, the fundamental benefits of antioxidants and anthocyanins in cosmetics have been proven by several researches in the past, however, there are not too many specific sources in the literature about the exact use of blueberry in cosmetics products, which is an area that needs to be focused on further. On the other hand, almost every research and experiment on blueberry benefits claim that the extracts are appropriate for cosmetic use, especially for an antioxidant base, so it can be assumed that blueberry is an important biomaterial that has potential in the cosmetic and personal care industry (Heberlé, Dos Santos and Magri, 2012).

Compared to many other groups of fruits, blueberries are richer in quality based on their nutraceutical value, which makes them a valuable biomaterial that can improve health from many perspectives. Blueberries have anticancer, anti-inflammatory, anti-diabetic, and antioxidant properties, which lead to the use of the fruit in many types of other products related to health such as drugs, feedstocks, personal care, and cosmetics products (Duan et al., 2022).

Blueberry is a fruit that has an effect against anti-aging, decreasing wrinkle formation and maintaining skin elasticity and smoothness, owing to its high level of antioxidants and polyphenols (Ivarsson et al., 2023). Moreover, it also has protective actions against hazardous sun lights including UVB lights. This makes blueberry a suitable biomaterial to be used in anti-aging products and sunscreen lotions (Schiavon et al., 2019). Another research conducted by Pambianchi et al. (2021), also supports that topical use of blueberry extracts has effects on decreasing and healing the skin damage caused by UVA, UVB, and UVC light while decreasing the oxidative stress and inflammatory reactions and maintaining the skin barrier. In addition to the sun damage, it is also mentioned in the same research that blueberry is also effective in reducing the skin damage caused by pollution (Pambianchi et al., 2021). These findings support the appropriate use of blueberry extracts in skin protection creams, sunscreens, nutritional and anti-aging products.

Valuable bio-active compounds of the blueberry are also said to be supportive of fighting acne, imperfections, and skin irritations. The antimicrobial and anti-inflammatory actions help the skin to balance the sebum level, clean clogged pores and minimize the size of open pores, prevent acne development, remove dullness, hydrate, and rejuvenate the skin, even more, it is found to be effective in healing the wounds (Pathan et al., 2022; Johnson, Lin, and Bongrad; 2010).

On the other hand, upcycling of wasted fruits is increasingly becoming an important process to achieve more sustainable production. Blueberry is one of these fruits that are available for upcycling. Blueberry leaves are known to be full of antioxidants as much as the fruit itself, so blueberry leaves are also important materials for cosmetic use (Ziemlewska et al, 2022). Additionally, blueberry seeds are also rich in vitamins E and C, antioxidants, carotenoids, phenols, and many more active compounds. The oil extracted from blueberry (and other red berries such as raspberry and marionberry) seeds becomes a valuable ingredient for the skin. Wasted parts of blueberries after juice production creates an opportunity for producing the powdered form of the blueberries that are included in skin care products such as soaps, and face and body scrubs (Wanninger et al., 2022; Parry et al., 2005).

3.1.1.3.2. Production and Processing of Blueberry

Anthocyanins, antioxidants, and polyphenolics are the most important substances of blueberry to be extracted, and blueberry skin is the part of the fruit where these compounds are found and can be extracted the most. After the production of juice, wine, and other food-related products, the waste of blueberries becomes a valuable source to obtain these ingredients. The most effective way to obtain these beneficial compounds is found to be the combination of heat treatment and citric acid solvent. Also, the juice production of blueberries should be done in traditional mechanical ways, and not with organic solvents, to protect the activity of anthocyanins (Lee and Wrolstad, 2004).

To mention the sustainability of blueberry extraction, high voltage electrical discharges, pulsed electric field, and ultrasound-assisted extraction are discussed to be greener methods than common methods such as maceration and soxhlet extraction, which require a high amount of solvents and risky for losing the value of active bio-compounds (Loncaric et al., 2020). Moreover, another research argues that microwave-assisted extraction is also more efficient in terms of the time required to obtain bio-compounds and amount of the solvents required to achieve a high yield (Routrey and Orsat, 2014). Glycerol is also determined as a greener solvent

which can increase the quality of extractions and longer time of the preservation of the valuable extracts, along with the support of ultrasound systems (Fu et al., 2022).

3.1.1.3.3. Pros and Cons of Blueberry in Cosmetics

Blueberry has a very high nutritional value compared to other fruits, and it can support several health conditions both as food intake and topical application. Also, it is a highly biodegradable natural source, which is highly environmentally sustainable. To this date, none of a specific or serious toxicity or allergic incident have been reported, which makes it a safe, healthy, and sustainable biomaterial for cosmetics (Yin et al., 2022).

One of the most specific disadvantages of blueberry use in cosmetics is the unstable nature of anthocyanins, which makes it hard to obtain optimal benefits from the fruit and more technological and scientific research is needed in that area. The requirement of solvents, heat, and chemical processes also prevents the whole process from becoming completely green, but several researchers are going on to discover greener methods compared to conventional ones (Yin et al., 2022). Another disadvantage of blueberry compared to other fruits is the higher cost and lower capacity of production, since blueberry harvesting is relatively new, and requires specific conditions such as weather and environment. The cost of planting and equipment makes blueberries sensitive and scarcely-found, compared to other highly-consumed fruits (Fang et al., 2020).

3.1.1.3.4. Companies Producing and Using Blueberry

Blueberries are used almost in every type of cosmetics and personal care products, from make-up to hair and body care. Frudia is a natural personal care brand from UAE, which sells fruit-based personal care products. In the company's product portfolio, there are blueberry-infused hydrating creams, serums, balms, cleansers, and toners (Frudia, 2023). 100% PURE is another brand that markets fruit-pigmented make-up products. The brand has blueberry-infused eye shadows, mascaras, lipsticks, blushes, and anti-aging oils (100% PURE ©, 2023).

There are other more known brands such as Sephora, Neve Cosmetics, Dr. Botanicals, Pupa, Farmacy, Glow Recipe, Truly, and Too Faced are serving many different blueberry-infused products such as lipsticks, masks, face and body creams, cleansers, scrubs, oils, nail polishes and fragrances (Douglas Italia S.p.A. ©, 2023; Sephora, Inc. ©, 2023).

The Upcycled Beauty Company is a startup that focuses on producing ingredients and beauty products from fruit wastes and byproducts and aims to transform all beauty industry ingredients

to upcycled materials, make these upcycled materials available to everyone, and inspire cosmetics and care brands to shift to more sustainable actions. The company has two different blueberry-based brands which are Blueberry NECTA© and Blueberry CRUSH©, which provide blueberry powder and oil produced from upcycled berries, which are wasted from juicing. These powders and oils are produced to be used as a natural material for several beauty products, along with also being cruelty-free, vegan, and certified (Upcycled Beauty Ltd ©, 2022).

3.1.1.4. Cacao

3.1.1.4.1. Cacao Plant in Cosmetics Field

Cacao is a valuable plant that is cultivated in tropical climate zones, mostly in African and Latin American countries. Cacao is the main raw material for chocolate production, and thanks to its rich nature of polyphenolic antioxidants, vitamins, minerals, and flavonoids, it has significant health benefits (Wickramasuriya and Dunwell, 2018). Cacao is a plant that has healing and preventing effects towards inflammation, cardiovascular diseases, cancers, and metabolic disorders, managing insulin levels, and having anti-inflammatory and anti-carcinogenic active bio-compounds (Andujar et al., 2012). That's the reason why, other than the food and beverage industries, it is also used as a biological raw material in other industries such as pharmaceuticals and cosmetics. Furthermore, while on the production process of chocolate, almost 90% of the cocoa beans turn out to be wasted byproducts such as pods, sweating, and shells, which emerges as a threat to the environment, but also a free raw material for use in different industries (Sanchez et al., 2023).

The antioxidants and polyphenols in cacao are effective in skin protection in past research. These compounds help cacao protect the skin from hazardous ultraviolet lights and eventually help delay skin aging and wrinkling (Kim et al., 2016). Skin aging is caused by sun-based lights, pollution, and poor nutrition, which can be supported by the extracts and valuable components cacao carries (Ferreira et al., 2021). From this point, it can be mentioned that cacao has anti-aging effects and sun protection properties, and therefore added to body care products such as moisturizing lotions, sun-screens, creams, and oils helping to fight these skin imperfections (Singh et al., 2020). Moreover, cacao also supports the hydration and moisturizing of the skin, protecting its thickness, decreasing the scaling, and maintaining the softness and healthy texture of the skin (Heinrich et al., 2006; Aburjai and Natsheh, 2003). Also, cacao has caffeine in its

nature, which also helps deal with fat accumulation and disarray in the cells, therefore reducing the undesired cellulite condition (Garcia et al., 2021).

In their research, Scapagnini et al. clarify that cacao and its byproducts are also used as functional treating ingredients for acne, psoriasis, and wound healing conditions, and bio-active compounds even act as a prevention agent for these conditions, along with healing (2014). All these findings from several academic types of research support the idea that cacao is a beneficial biomaterial that helps deal with many skin conditions and is appropriate to be added to cosmetics and personal care formulations for the skin.

Other than skin care applications, cacao also takes part as a biomaterial in hair care products. Ingredients of cacao such as antioxidants, caffeine, vitamins, and minerals can help stimulate hair growth and fight hair loss (Mustarichie et al., 2022). The research of Yusof et al. (2022), also supports the idea that cacao byproducts such as shells and pods are appropriate to be used in hair gel formulations. In addition to the support of hair loss, cacao butter is also used in hair care products as a softening and protection agent (Patil, Mundecha, and Patil, 2023).

3.1.1.4.2. Production and Processing of Cacao

Cacao byproducts are used as a material in cosmetics more than the bean itself since there is a high amount of potential byproduct waste. Byproducts of cacao that can be used in products can be listed as cacao husks, hulls, pulps, shells, and sweating. These by-products are produced with the methods of fermentation, drying, and toasting (Sanchez et al., 2023). Cacao husks are the part of the cacao that are mostly used for cosmetic and personal care group products. Extractions from cacao husks for cosmetic formulations are carried out with solvents such as ethanol, acetone, and water (Soares and Oliveira, 2022). Cacao butter and cacao powders are two main material forms of cacao other than extracts and these two forms are also added to cosmetic products for their nourishing benefits. Cacao butter and powder are obtained from the cacao bean production process which is listed from beginning to end as cleaning, micronizing, breaking, alkalization, roasting, and grinding. After these processes, an additional process of pressing is needed to obtain cacao butter and pulverizing for cacao powder (Scapagnini et al., 2014).

3.1.1.4.3. Pros and Cons of Cacao in Cosmetics

Cacao is a plant that creates large amounts of bio-wasted byproducts and these products are rich in beneficial minerals, vitamins, and proteins, for the skin. So there is a huge available source

for using these products as cosmetic biomaterials, and it is one of the few ways they can be valorized since especially hulls can be toxic on oral consumption and cannot be valorized as feedstocks (Švarc-Gajić et al., 2023). Other than this potential, cocoa has several benefits to various systems in the body (cardiovascular, digestion, etc.) and different skin conditions such as aging, dry skin, acne, and wound healing. This supports the fact that cocoa is a healthy and sustainable raw material and its use in cosmetics is valid (Gasser et al., 2008). As mentioned in the previous section, cocoa extracts are generally obtained with several solvents, which may lead to a discussion about the process sustainability, but there are also greener methods such as water extraction methods to obtain cocoa material for cosmetic products (Švarc-Gajić et al., 2023). Additionally, cocoa harvesting is very important for small farmers in African countries, both economically and environmentally. Cocoa farming is one of the main sources of revenue in many African neighborhoods and cocoa cultivation helps the soil become more productive for other plants and is also effective in increasing the animal biodiversity in the farming zone, which supports sustainable production both economically and environmentally. Cocoa farming is very important to maintain the well-being and affluence of many people in these low-income regions (Franzen and Mulder, 2007; Ntiamoah and Afrane, 2008).

3.1.1.4.4. Companies Producing and Using Cacao in Products

Cocoa, butter, its byproducts, and chocolate are the forms of the plant that can be seen on the skin and hair care ingredients lists. All Things O'Natural is a small family brand from the USA, that sells cosmetics and hair care products that consist of natural ingredients. The brand provides cocoa-infused skin cleansers, face scrubs, and hair conditioners (All Things O'Natural ©, 2023). 100% PURE is another cosmetics brand that provides nature-based, cruelty-free, and environmentally sustainable products intending to protect the ecosystem, plants' and animals' wellbeing. In the brands' portfolio, there are several cacao-based products ranging from cleansers, face and body scrubs, bronzers, and moisturizer masks (100% PURE ©, 2023). Other brands such as Too Faced, Lush, Fresh, Colorbar, Dot & Key, The Lip Balm Company, The Beauty Co, Perricone MD, Balmyard, and many other beauty brands sell chocolate and cacao-based make-up, skincare, and hair care products ranging from hair creams to lip balms and creams (Devash, 2017; Singh, 2022; Atkinson, 2019).

SpecialChem is a material and ingredient platform that provides different suppliers for various raw materials. On their website, cocoa extract and cocoa shell powder are two of the biomaterials that companies sell which are formulated for cosmetics and personal care products. The companies that provide cacao extract and shell powder are listed as A&E Connock, Bionat

Consult, Greenphyt, Lessonia, Vantage, Assessa, Akott, Biogründl, BotanicalPlus, Mibelle Biochemistry, and many more. These companies provide materials that are helpful in cosmetic products for anti-aging, exfoliating, anti-acne, moisturizing, anti-stress, and smoothening purposes (© SpecialChem, 2023).

3.1.1.5. Citrus Fruits

3.1.1.5.1. Citrus Fruits in Cosmetics Field

Citrus fruits are highly present in our daily lives, thanks to their pleasant tastes, smells, and valuable nutritional content including vitamins, minerals, and acids. Citrus fruits can be listed as lemon, orange, lime, cumquat, pomelo, mandarin, grapefruit, and tangerine, along with other derivatives (Arouma et al., 2012). Although citrus fruits are mostly known and used as food material, they have a huge potential to be applied in cosmetics as a biomaterial, due to their valuable content and many health benefits. Citrus are consumed in large quantities, meaning a very high level of waste peel is created. Citrus peels are full of bioactive nutrients, vitamins, and minerals that are important for well-being (Khan et al., 2021). These waste peels emerge as a perfect opportunity as a material for cosmetics, supporting both green practices and a healthier care routine.

Citrus fruits are known to be full of vitamin C, antibacterial, anti-inflammatory, anticancer, and highly rich in antioxidants. These significant nutritional values make citrus fruits applied widely in medicines and supplements. All of these benefits are also found to be effective for skin and overall body health, thus citrus fruits are appropriately applicable to cosmetics and personal care (Adenaike and Abakpa, 2021). Citrus fruits are used very widely in the form of essential oils, as pleasant fragrances, and as aroma givers in mouth care products, but it is also seen in hair products, and several lotions or creams for the body and face.

Citrus fruits are effective in fighting skin aging and reducing wrinkles. This is thanks to the citrus extracts and essential oils that are beneficial for healing the skin elasticity and decreasing the skin imperfections due to solar radiation. Moreover, citrus fruits are also found to have anti-melogenic properties and are beneficial for skin whitening (Prommaban and Chaiyana, 2022; Apraj and Pandita, 2016). These findings support that citrus application on body lotions and creams is proper. Moreover, past experiments concluded that citrus extracts and oils are capable of protecting skin against UV lights and decreasing skin pigmentation, with the help of vitamin C and antioxidants for reviving skin. That’s why citrus is applied to sunscreens and after-sun products (Puglia et al., 2014).

In some past research, experiments have shown that having antimicrobial and anti-inflammatory properties, specific citrus extracts and essential oils are also beneficial for healing acne and other skin imperfections caused by inflammation or bacteria (Kim et al., 2008; Hou et al., 2019). These findings can be said as foundations of lemon, orange, and grapefruit-based skin cleansers or creams. On the other hand, citrus fruits are widely used in facial serums as vitamin-C supplements for the skin. High antioxidants, vitamin C, and citric acid make skin healthier in general, healing damages, decreasing imperfections, and making skin brighter (Rani et al., 2019). In addition to these, lime juice is found to be effective in cleaning dandruff, and dead skin cells, decreasing rashes, and helping to grow new tissue. These aspects support the use of citrus in hair and body shower products (Mohanapriya, Ramaswamy, and Rajendran, 2013). Another research also defined the potential and beneficial activities of lemon extracts on the skin as skin conditioning, humectant, absorbing, masking, and perfuming (Klimek-Szczykutowicz, Szopa, and Ekiert, 2020). All of these benefits prove that citrus fruits are very appropriate biomaterials that are used commonly in cosmetics and care, promoting healthier product options and more sustainable production cycles.

3.1.1.5.2. Production and Processing of Citrus Fruits

To be added to products, citrus fruits mostly need to be transformed into essential oil form, which needs several physical or sometimes, chemical processes. Essential oils are extracted from the peel, which is obtained after fruit consumption. Peels are dried with heat and the hydra-distillation method is used for extracting essential oils (Prommaban and Chaiyana, 2022). In several other researches, organic solvents have also been used to extract essential oils from peels, and then the solvents dried up to obtain the bioactive extract alone (Maheshwari and Singh, 2023; Rehman, 2006). In addition to all these methods, depending on the purpose and target product, extra heating and filtration processes are also applicable. Furthermore, citrus derivatives can and are also used in the form of peel water, peel powder, or juice in products, other than essential oil form (Klimek-Szczykutowicz, Szopa and Ekiert, 2020).

3.1.1.5.3. Pros and Cons of Citrus Use in Cosmetics

Citrus fruits are very abundant in consumption, which means a huge amount of leftovers are available for processing into several uses. Since citrus wastes are organic and natural materials with many benefits mentioned above, using citrus wastes as biomaterials inside cosmetics and personal care products is a good example of a circular approach. Citrus essential oil helps many skin issues in ones, such as anti-aging, acne, cleansing, and shining, as a multi-use and natural

element. On the other hand, conventional methods are considered low-cost, which helps processing and application economically sustainable, alongside costless raw material. A few drawbacks of citrus use can be mentioned as the need for more clarifying and deep research to assess if there are potential risks of citrus use, which have not been clearly defined yet (Panwar et al., 2021). As mentioned in the processing part, chemical use in the extraction of essential oils, even if they are organic, is controversial, in terms of obtaining completely green production methods.

3.1.1.5.4. Companies Producing and Using Citrus in Products

Citrus is added to many products in several brands. Vita Lake is an Italian natural cosmetics brand that sells products with materials harvested around Garda Lake. The brand has a wide collection of lemon-infused products ranging from face and body creams, shampoos, shower gels, and glow lotions (©Vita Lake LC Cosmetics, 2023). Circcell is a US-based environmentally conscious and cruelty-free brand selling cosmetic and care products. The company provides citrus-based creams, vitamin serums, masks, and cleansing milk to hydrate and brighten skin, control acne, and give the skin fundamental nutrients (©Circcell Skincare, 2023).

Along with these sustainable and conscious smaller brands, larger brands such as Clarins, The Body Shop, Ole Henriksen, Vitaskin, Burt's Bees, Pixi, MAC and many more provide lemon-infused products for exfoliating, cleansing, and shinier skin (Wright, 2021; Selvanayagam, 2021). On the other hand, The Body Deli, Neutrogena, Herbal Essences, Molton Brown, Malin and Goetz, and many other cosmetics brands serve products with grapefruit extracts to fight skin imperfections and improve the skin as a whole (Ojeifo, 2020).

3.1.1.6. Coconut

3.1.1.6.1. Coconut Plant in Cosmetics Field

Coconut is a tropical fruit which is harvested widely in Asian countries. Mostly known as a food source, the meat and milk of the fruit are also used commonly for many other areas as alternatives. Skin and hair care are some of these areas where coconut elements have been used as traditional care. Coconut milk and oil are recently in an increasing trend as healthy biomaterials that are used by many known cosmetics and care brands. The main reason for this trend is the various benefits of coconut's ingredients to general health, skin, and hair. With the perspective of healthy and sustainable cosmetics, virgin coconut oil (VCO) is becoming the

most valuable source that is applied to cosmetics, thanks to its numerous therapeutic benefits and containing various vitamins and nutritious essential acids for the body as a whole (Kappally, Shirwaikar and Shirwaikar, 2015).

Coconut oil is the main ingredient that is infused into cosmetic products, which is then followed by coconut milk. Recently, virgin coconut oil-infused cosmetics are very common on shelves, varying from shampoos, creams, lip balms, body scrubs, sunscreen lotions, soaps, and massage oils. The main benefit of VCO that is used in body and hair products is the moisturizing capability. VCO has proven effects on hair hydration and softening, skin smoothening and moisturizing, and healing cracks on lips or face (Pandiselvam et al., 2019). In addition to moisturizing benefits, coconut oil has also proven to be protective against UV lights and works as a filter. Moreover, it is also helpful in the case of sun damage, softening the skin and renewing the tissue with moisturizing. The benefits of VCO make it a very valuable natural biomaterial that is appropriate for use in sunscreen lotions (Widiyati, 2017). Furthermore, hair damage due to sun exposure is another area where coconut oil is used as treatment. Due to UV protection, moisturizing capabilities, and damage repair, coconut is included widely in hair care products for healing, softening, strengthening, and maintaining the texture and color of the hair (Kaushik, 2022).

Past research and experiments conducted on coconut compounds have also identified the benefits of coconut milk on skin cleansing. In literature, coconut milk is claimed to be effective in reducing blackheads and acne on the face and body, supporting the purity of the skin thanks to its rich content of beneficial fatty acids, antiseptics, and antimicrobial properties. These findings support the idea of appropriate coconut usage in skin cleansers and tonics. Moreover, experimental research also concluded that coconut milk helps to decrease hyperpigmentation and helps reduce uneven color patches on the skin (Kusstianti and Usodoningtyas, 2020).

Finally, VCO is also effective in healing skin irritations, allergies, inflammations, trauma wounds, and infections since it has anti-inflammatory, analgesic, and antioxidant properties, along with the mentioned antimicrobial effects on healing acne and black spots. These benefits make VCO-based skin products very promising for those who are seeking natural and non-hazardous remedies (Varma et al., 2019). All of these mentioned functions of coconut show that the fruit and its derivatives are favorable bio-based sources for cosmetics and personal care applications.

3.1.1.6.2. Production and Processing of Coconut

As mentioned above, coconut is used in skin and hair care products in the form of milk, powder, and oil, preferably virgin coconut oil. While coconut milk can be directly obtained without any other special process, extraction of VCO needs specific special treatments. The main traditional methods to extract VCO can be listed as heating, and hydraulic press which are dry physical extraction methods without the use of any chemicals. Additionally, fermentation and enzymatic processes are other kinds of wet methods to obtain VCO from mature fruits (Satheesh, 2015). All of these methods are possible green processes since they can be conducted without the need for any chemicals, but there are also other previous experiments and research in the literature that were conducted using some sort of chemicals to obtain VCO (Harimurti, Rumagesan, and Susanawati, 2020).

3.1.1.6.3. Pros and Cons of Coconut in Cosmetics

There are profound benefits of coconut used in cosmetics, and the most important facts prove that coconut is completely natural, low-cost, abundantly harvested, and nontoxic material that has not shown serious reactions till that day from past experiments, so it is a quite reliable, stable and safe material which has numerous health benefits, especially on skin and hair. There are just very few numbers of participants in experiments claim they have slight allergies and reactions to the experimental lotions including coconut oil, which means, that for people who have specific allergies, coconut-based cosmetics may not be optimal options (Satheeshan, Seema, and Manjusha, 2020). Moreover, the processes needed to obtain and add coconut milk or oil into products are significantly green and natural, including more physical methods than chemical ones as mentioned before in the processing section.

3.1.1.6.4. Companies Producing and Using Coconut in Products

Several companies produce virgin coconut oil and sell it to various companies to be used in products, including cosmetics and the personal care industry. Cargill is a US-based company that aims to create sustainable materials, production, and lifestyle as a whole. One of the main products the company markets is coconut oil, which is used for beauty and cosmetics applications (Cargill Incorporated ©, 2023). Siamplus is a Thai company that has professionalized in coconut oil production and sells coconut oil and coconut-based body, hair, and mouth care products and soaps (Siam Plus Coconut Oil Co. Ltd, 2023).

Several brands focused on natural and bio-based materials in their cosmetics products, along with bigger companies adding coconut to their famous products. Rabiah is an Indian company and all of the products they sell are coconut-based, including scrubs, balms, hair products, and body lotions (© Rabiah Coconut Products, 2016). RAWW is an Australian company that markets skin and body care products that are formed by plant and fruit-based. The company offers a wide variety of coconut-infused products such as moisturizers, nail polishes, makeup tools, balms, and creams (© RAWW Cosmetics, 2023). Coconutoil Cosmetics is a Hungarian company that sells care products with nature-based ingredients and they offer many different products such as body lotions, sunscreens, balms, and scrubs (Coconutoil Cosmetics, 2023). Along with these specialized sustainable bio-brands, larger companies such as Herbal Essences, OGX, and The Body Shop, and relatively smaller ones such as Sol de Janeiro, Huda Beauty, Coco & Eve, Aveda, and many more serve a high variety of personal care products to satisfy the need of their environmentally and health-concerned customers (Baijal, 2022; Bhatia, 2021).

3.1.1.7. Coffee

3.1.1.7.1. Coffee Plant in Cosmetics Field

Coffee is a plant that is harvested widely in Africa, Asia, and some Middle Eastern regions. Coffee is recently one of the most famous and loved functional beverages, having pleasant color, aroma, and texture. Coffee has these various benefits thanks to the valuable bio-compounds in its nature such as alkaloids including caffeine, phenolic, and chlorogenic acids. Having these bio-active compounds creates a huge potential for coffee to take part in many different types of industrial products as a healthy and cost-effective biomaterial. Besides, in the production process of coffee beverage, almost 90% of the plant becomes waste and pose a threat in terms of environmental sustainability. These byproducts of coffee emerge as a very valuable source of biomaterial for many industries, primarily for cosmetics and personal care since almost all of these leftovers carry high amounts of precious substances (Rodrigues, Oliveira and Alves, 2023).

Coffee byproducts can be listed as pulp, skin, bean, silverskin, parchment, and mucilage. All of these byproducts carry a substantial amount of valuable compounds that are considered anti-inflammatory, anticancer, antimicrobial, antiviral, and anti-aging and contain a large variety of antioxidants. All these byproducts and substances create a vast potential for topical use in personal care products, helping to fight several health issues (Mendes dos Santos et al., 2021). Past research conducted by green coffee beans showed that lipids extracted from the bean have

remarkable protection capabilities against ultraviolet lights and protect the skin barrier. Moreover, the compounds obtained from these lipids are also effective in moisturizing the skin and soothing it. Therefore, coffee extracts are very important bio-sources that can be used in sunscreens and moisturizers (Wagemaker et al., 2011).

Coffee silverskin is one of the byproducts of coffee that many recent researches have conducted about. Silverskin is produced in the phase of roasting and contains many beneficial ingredients for skin health. In a recent research by Iriondo-DeHond et al. (2016), it has been found that extracts from silverskin have positive effects on skin aging, reducing oxidative stress on the skin and slowing down wrinkling. The extract shows protective actions against UVC radiations, protects the skin barrier, and maintains skin health. Further research conducted (Grigolon et al., 2023) also showed that extracts from coffee silverskin are also effective in reducing skin sensitivity, protecting against redness and skin irritation caused by dehydration, relieving itchiness, and fastening the skin regeneration after irritations, moisturize, smoothening and homogenize the skin tone.

Caffeine is an alkaloid substance which is found intensively in coffee. While the most known effects of caffeine are to reduce tiredness and increase energy levels, it has also many benefits to the skin. Caffeine, along with the other bioactive compounds and acids that exist in coffee, is found to be effective as an anti-cellulite agent, reducing the unwanted view of imperfect and fatty tissue and decreasing the size of accumulated fat cells (Velasco et al., 2008). Therefore, caffeine obtained from coffee is appropriate for use in anti-cellulite creams and oils or other types of body care products. On the other hand, caffeine also supports hair growth by inhibiting several enzymes that make hair fall and become thinner. The past experiments showed that creams and shampoos including caffeine extracts supported hair growth and reduced fallouts. These results prove that coffee-based hair care products have many benefits for the scalp (Herman and Herman, 2013).

3.1.1.7.2. Production and Processing of Coffee

There are several methods to produce coffee-based biomaterial from the byproducts. The past experiments in the literature show that nearly all of the extraction methods contain a particular amount of chemicals used to activate bio-compounds. However, in their research, Mendes dos Santos et al. (2016), identify two main methods of obtaining coffee byproducts, which are the dry method, containing drying, hulling, peeling, and shaping, and the wet method containing pulping, washing, fermentation, and polishing, different than the dry methods. Dry methods are

identified as more environmentally-conscious methods, since with wet methods, there are more anti-nutritional and wasted output. It is also mentioned that more research and development is needed to reach a more sustainable chain of coffee production. Additionally, the chosen extraction method can change the chemical composition of targeted compounds, therefore there are still limitations in how the topical use of coffee byproducts should be determined (Blinová et al., 2017).

3.1.1.7.3. Pros and Cons of Coffee in Cosmetics

Coffee is a product which has been consumed by almost everyone, which makes it a trusted product. On the other hand, compared to many other biomaterial options for cosmetics, there is more research present in the literature about the safety of coffee used in products, and almost all of this research found that it's safe to use coffee extracts in cosmetics since no significant reactions or problems have been detected yet (Rodrigues et al., 2015; Bessada, Alves and Oliveira, 2018). Another advantage of coffee is the amount of reusable and nutrition-rich byproducts created after turning coffee into beverage form. The leftovers of coffee emerge as a beneficial biomaterial and the use of these byproducts also supports environmental activities and decreases footprint, supporting economic savings, and transforming the coffee biomaterial used in the cosmetics process greener overall. In contrast, the negative probable side effects of caffeine are known to everyone, and there is not much research to define the cytotoxicity of caffeine to the skin, what ideal dosage of the caffeine for the skin, and the valorization of bioactivities. Plus, there is very little proven information about the side effects of caffeine on the skin even though it is already used frequently (Herman and Herman 2013; Kaisangsri et al., 2020).

3.1.1.7.4. Companies Producing and Using Coffee

Kaffee Bueno is a Danish startup company that produces coffee extractions to be used in cosmetics and nutraceuticals, then collects leftovers and upcycles the coffee to be recycled coffee oil. The company also sells personal care products they produce with the use of these extracts and coffee oil. They aim to decrease organic waste created by coffee production, eliminate greenhouse gas emissions, and adopt sustainable production (Kaffee Bueno ApS, 2023). Coffee-eco is a Greek startup upcycling wasted coffee grounds to extract antioxidants and caffeine to be added to skincare products. The company is also partnering with hotels and restaurants to manage and valorize their wastes, and using packaging with bioplastics. They

aim to decrease their carbon footprint and develop environmentally friendly skin care products (Coffe-eco ©, 2023).

Along with these startups, coffee-based bio-compounds use is very frequent in larger brands too. Caffeine is the most used coffee-based ingredient in the products. Brands such as Tom Ford, Origins, Sephora, La Roche Posay, The Ordinary, Marc Anthony, The Body Shop, Paula's Choice, Drunk Elephant, Nykaa, The Sugar, Mcaffeine, and many more brands sell caffeine-originated body scrubs, face masks, perfumes, balms, and hair/shower products, exploiting the energizing, smoothening, anti-aging, and cleansing capabilities of coffee (Stephan, Milne and Fellizar, 2022; Duggal, 2022; Leong, 2021).

3.1.1.8. Cucumber

3.1.1.8.1. Cucumber Plant in Cosmetics Field

Cucumber is a type of vegetable that is harvested in a wide variety of geographical areas including Asia and Europe. Cucumber is a vegetable commonly consumed as a fresh food or in the form of a pickle. Its high level of water, vitamin, mineral content, low calorie, and being an affordable food alternative make cucumber preferred by many people in the world. Moreover, cucumber has numerous health benefits to the digestive and cardiovascular systems, metabolism, and overall skin texture. That's the reason why, along with its consumption as a food source, cucumber has been used as a cosmetic, personal care, and pharmaceutical ingredient, even since ancient times as a traditional remedy for several conditions. Having a nature rich in antioxidants, and polyphenols and is antimicrobial, anti-inflammatory, and antiallergenic cucumber sets a very appropriate biomaterial example for the use of cosmetics and personal care products (Uthpala et al., 2020; Mallick, 2022).

One of the cosmetics areas in which cucumber is present as an ingredient is sun-protection-related products. Cucumber is found to be effective in protecting the skin against UVA, UVB, and UVC lights, have a healing effect on sunburns, scars, and irritation caused by sun exposure, and freshen, soothe, and rejuvenate the skin afterward (Garg, Singh, and Garg, 2016). Having rich in vitamins A and C and various antioxidants helps cucumber to become significantly effective in protecting, healing, and soothing the skin. Furthermore, these mentioned bio-active compounds are also effective in decreasing wrinkle formation and sagging, maintaining the elasticity and smooth texture of the skin, and acting as anti-aging agents (Septiyanti and Meliana, 2020). In addition to anti-aging and photo-protection activities, the relevant minerals and bio-active compounds are also proven by many past researches to be acting as skin-

whitening agents, decreasing the browning effects caused by exposure to dirt, sun, and bacteria from the environment (Mukherjee et al., 2013).

As it has been known for many years, cucumber helps to reduce dark circles and puffiness around the eye area. Moreover, it is effective in cleaning and opening the pores, moisturizing the skin, and preventing acne formation (Akhtar et al., 2020). These benefits of the cucumber prove its use in eye and face creams, masks, and oils. Additionally, vitamin C, antioxidants, caffeic acid, and ascorbic acid substances in cucumber also help control the sebum level of the skin and reduce the occurrence and severity of pimples, acne, or other imperfections and irritations, by cleaning and hydrating the skin in a soft way (Valsan, A., 2013). All these findings from research support that cucumber is a highly beneficial biomaterial that increases the value of cosmetics products and helps several conditions related to the skin to be improved. Moreover, cucumber also includes glycolic and lactic acids, which will act as natural exfoliants and remove dead skin cells to renew the skin and give it a more energized and shiny. This renewing process will also help to fight blackheads and whiteheads with the support of Alpha hydroxyl acids and other antimicrobial and anti-inflammatory agents. These bio-compounds also support the skin to stay healthier overall by increasing the production of collagen and elastic fibers and preventing skin from being thinner and vulnerable to environmental threats (Ugwu and Suru, 2021).

3.1.1.8.2. Production and Processing of Cucumber

Several forms of cucumber can be a part of cosmetic products and they can be listed as cucumber fruit extract, fruit water, peel powder, seed extract (seed oil), juice, and the fruit itself. While as a traditional method, cucumber has been used as a raw fruit or in mechanical other forms such as drying and peeling, without chemical combination, the cucumber extracts that are added into cosmetic products are mostly extracted by organic or inorganic solvents including propylene, glycol, and water. Instead, cucumber peel powder extraction is carried out with the help of hydro-alcoholic solvents (Belsito et al., 2012). Cucumber seed oil, another common cosmetic material form, can be obtained by the sun-drying, grinding, and soxhlet extraction and boiling methods (Ifeoma et al., 2021). The level of environmental sustainability of these methods is subject to discussions but according to the reports, the use of the mentioned solvents is considered safe.

3.1.1.8.3. Pros and Cons of Cucumber in Cosmetics

Cucumber is a plant that helps prevent a wide variety of health and skin conditions, especially compared to other biomaterials mentioned in this thesis. Cucumber has supportive actions on almost every skin type ranging from oily to dry skin, helping with acne, anti-aging, dullness, and wounds, and protecting the skin from the sun. Since it is helpful in even contradicting conditions, it is a plant that can be used in almost every type of product. Plus, cucumber is cultivated in very large geographies and thus it is an abundant biological material, which is also significantly affordable (Ergun and Susluoglu, 2019). On the other hand, from the past studies, there are no important side effects detected such as allergies, or toxicity, excluding very low levels of discomfort. However, it is suggested in the reports that cucumber-based skin products should go through more safety assessments, especially for people who have specific skin diseases such as psoriasis. These findings prove that cucumber is a safe and healthy biomaterial that is commonly used in skin care products (Akhtar et al., 2011; Belsito et al., 2012).

3.1.1.8.4. Companies Producing and Using Cucumber

Cucumber is one of the most widely-used biomaterials in cosmetics and personal care products, ranging from make-up to face care and hair care. Many known brands have several products that have cucumber extracts inside. Garnier's Fructis series has cucumber-infused shampoos and conditioners which are beneficial for combatting oily hair (Garnier LLC ©, 2019). Lush is also another natural and cruelty-free cosmetics and care brand that sells cucumber-based cleansing shower gels and eye pads (Lush, 2023).

Several other bigger brands market different types of cucumber-included products. These can be listed as Kiehl's Cucumber Herbal Alcohol-Free Toner, Mario Badescu Special Cucumber Lotion which is produced as an acne-healing and refreshing product, Peter Thomas Roth Cucumber Gel Mask Extreme Detoxifying Hydrator, which is a hydrating and soothing mask, Yes to Cucumbers Calming Micellar Cleansing Water (Goldman, 2023). Sephora, Boots, Bioderma, Pixi, Burt's Bees, The Body Shop, Glow Recipe, Farmacy, Tula, and many other brands also have many products in their portfolio that has cucumber extracts inside (Sephora USA ©, 2023; Maddix, 2022).

3.1.1.9. Eucalyptus

3.1.1.9.1. Eucalyptus Plant in Cosmetics Field

Eucalyptus is a tropical plant that is cultivated in Australia and Mediterranean countries and consists of more than 900 different species. Eucalyptus has been used as a natural and traditional source of food, medicine, and wood crafts for centuries in the past and recently it's been consumed by many different areas of life at an increasing rate, such as planting, arts, pharmaceuticals, and cosmetics (Vecchio, Loganes and Minto, 2016). Essential oil is the most widely known and used form of eucalyptus plant, which carries various health benefits, being anti-inflammatory, antibacterial, antifungal, and antioxidant. These are the facts encouraging the eucalyptus essential oil to be added to several products in pharmaceutical and cosmeceutical products (Hayat et al., 2015). Eucalyptus essential oils are extracted mainly from the flower and leaves of the eucalyptus plant, which has several important but volatile bio-active compounds, which require sensitive chemical extraction, water, and steam distillation methods (Salehi et al., 2019).

Eucalyptus is a plant which has a high level of antibacterial and antimicrobial bio-active compounds. Due to the existence of these compounds, eucalyptus essential oils have been used as a traditional treatment material for centuries, and recently, these bioactive compounds are helping to fight acne problems on the face and body. Additionally, it also helps balance the oil on the skin. Therefore, eucalyptus oil is used as a safe biomaterial which is considered an anti-acne agent, and therefore added in anti-acne and sebum regulating products (Bhatt et al., 2011; Athikomkulchai et al., 2008). Moreover, these organic substances in eucalyptus oil also help to cleanse the skin by opening clogged pores, eliminating dirt and sebum exfoliating dead skin cells, and renewing the skin tissue (Alajeel, Hasan, and Faisal, 2020). Also, another research indicated that facial cleansers, sun lotions, and moisturizers with eucalyptus extracts inside are helpful and suitable for acne-prone and sensitive skin to regulate the condition (Isoda et al., 2015).

In past research, eucalyptus bio-active compounds such as phenolic acids, flavonoids, and other antioxidants have shown protective effects against UV lights and photo aging related to exposure to these lights. Therefore, it has been concluded that topical use of eucalyptus extracts has protective effects towards sunlight, reduces wrinkle formation, skin dryness, and aging, and maintains the thickness of the skin (Almeida et al., 2022; Park et al., 2018). In addition, UV-

light protection is also supportive of inhibiting the depigmentation of the skin and maintaining its natural color tone (Huang et al., 2015).

Essential oils have a significant level of support for moisturizing and hydrating skin and eucalyptus oils are one of these kinds of oils which is used with moisturizing aims. In past research, especially for dry skin types and skin with dermatitis disease, eucalyptus extracts are effective in moisturizing and healing effects on these dryness, scaling, and dermatitis conditions, supporting the fact that eucalyptus has smoothening and softening substances (Ishikawa et al., 2013; Mori et al., 2018). Likewise, this moisturizing effect of eucalyptus was also found to be valid in dry scalp conditions which may also include different kinds of dermatitis conditions on the head area, which supports the idea that eucalyptus use in hair care products such as lotions is valid (Takagi et al., 2018).

3.1.1.9.2. Production and Processing of Eucalyptus

There are several different methods to produce eucalyptus essential oils. The most widely used methods can be listed as steam extraction, solvent extraction, hydro-distillation, and supercritical fluid extraction (Zhao and Zhang, 2014). Compared to these conventional method which requires chemical or organic solvents and carry the risks of losing the value of bioactive compounds, there are greener methods to extract eucalyptus such as microwave-assisted extraction, enzyme-assisted extraction, and ultrasound-assisted extraction. These methods set good examples of extraction methods in terms of reducing less waste, decreasing the risks of the capabilities of antioxidants, and costing less in the end (Gullón et al., 2019). Water distillation is another method that is used to obtain eucalyptus oil, which is considered a cost-effective and available method that does not require extra investments and chemical use (Abdul-Majeed, Hassan, and Kurji, 2013). Before applying all these mentioned methods to extract eucalyptus oil, the plant generally needs to go through several mechanical methods such as air-drying, milling, chopping, and filtration to obtain the optimal form of substance to be extracted (Becker et al., 2023).

3.1.1.9.3. Pros and Cons of Eucalyptus in Cosmetics

Eucalyptus is a natural source that has numerous benefits to human health and skin in general, being antioxidant, anti-inflammatory, antibacterial, moisturizing, and renewing, which makes it a suitable biomaterial that can be used in different industries including cosmetics and personal care (Dhakad et al., 2017). Eucalyptus essential oil has been used as a beauty and medicinal ingredient for centuries, which implies it is a trusted biomaterial by society (Hayat et al., 2015).

Assessments carried out for essential oil safety have shown that it is considered a safe biomaterial (Becker et al., 2023). Even though the main conventional methods to extract essential oils require several solvents, there are various green and inexpensive methods to obtain the oil without the use of chemicals, overheating, and risks of losing the activity of compounds, as mentioned in the previous section.

3.1.1.9.4. Companies Producing and Using Eucalyptus in Products

Eucalyptus essential oils and extracts are used in different types of product groups in the cosmetic industry ranging from body creams and lotions to perfumes and hair care products. 100% PURE natural cosmetics brand sells eucalyptus-infused lip balm, bath scrub, shampoo, conditioner and shower gel. The brand also deodorants which uses eucalyptus extracts as freshening smell agent (100% PURE ©, 2023). Liage is another natural ingredient-based and cruelty-free specialized beauty brand who have a eucalyptus collection including body and hand creams, peeling cream, shower gel, and moisturizer (Liage ©, 2023). Nabila K is a luxury beauty brand that aims to sell beauty products that are free of hazardous chemicals and animal testing. The brand has eucalyptus-included soaps, shower gels, and cleansing wipes in its product range (© NABILA K Cosmetics Inc., 2023). Other brands like Molton Brown, Necessaire, Yuzu, Noshinku, Salt & Stone, Grove Co., Mrs. Meyer, Little Moon, and many other brands have eucalyptus-based cosmetic products (Grove Collaborative, 2022; Thomas, 2023).

Suzano is an innovative brand that produces extracts and other materials from eucalyptus plants. With the extracts of eucalyptus, they produce pulp, fabric, paper, and other products that can be used as innovative and natural materials (Suzano, 2021). The pulp and oil Suzano produces carries a potential of material that can be added to cosmetic formulation, and the company is also considering partnerships to reach this aim (Behrens, 2022).

3.1.1.10. Olive

3.1.1.10.1. Olive Plant in Cosmetics

Olive is a type of fruit that is commonly harvested in Mediterranean regions and Asia and used as a healthy food source in the whole world. Apart from being widely consumed as a food in the form of fruit itself, almost 90% of the olives harvested are processed to produce olive oil. Matter of fact, the olive oil industry is one of the industries where a significant amount of waste is created, including seeds, leaves, and oil-based liquids. This waste creates an opportunity to

appreciate the unused bio-products that are left over from olive oil production. It is known that these wastes of olive fruit are rich in the same beneficial acids and components, which attracts other industries, such as food, pharmaceutical, and cosmetics, who are willing to use olive and its wasted byproducts as biomaterials (Cádiz-Gurrea et al, 2021).

Olive has been used extensively as a natural and traditional beauty ingredient in past years, and recently, widely used as a bio-substance in personal care and cosmetics products. This use is due to the high nutritional value of the olive, including organic fatty acids, polyphenols, and vitamins. While olive oil is the most known and widely used form of oil that is used as a substance in cosmetics, the bioactive compounds mentioned are also found in byproducts such as leaves and seeds, and therefore, these parts of olive are also used as biomaterials in cosmetics. These organic fatty acids, bio phenols, vitamins (A, C, E), and squalenes inside olive and byproducts provide the fruit to be an effective antioxidant, antimicrobial, softening, and healing agent, which are important for personal care and cosmetic products (Gorini et al., 2018).

As mentioned before, olive oil is the most commonly used form of olive in cosmetics and personal care products. It is possible to see olive oil-based products very often, since it is used extensively in hair care and skin care products, mostly in the form of creams. This wide use of olive oil in cosmetics is also due to the trust and positive perception of consumers for olive oil. Olive is a natural and healthy ingredient, having been used from ancient ages safely and beliefs of it helping to many health conditions are the widespread opinions of consumers about olive cosmetics (Gambaro et al., 2014).

One of the most important benefits of olive extracts to the skin can be defined as skin protection from sunlight (UVA, UVB). Several past researches and experiments found that olive extracts and oil are effective in protecting the skin against harmful radiation, therefore, supporting the skin to maintain its elasticity and healthy tissue. Moreover, it is known that these lights also cause skin aging and wrinkling. From this point of view and other supporting experiments, it is clear that olive-based products help prevent skin aging and reduce wrinkles. These protective bio-compounds also prevent skin from irritations and pigmentation. These findings from past research demonstrate that the use of olive-based biomaterials in cosmetics and personal care products is beneficial. That’s the reason why this material is very suitable for skin care creams such as sunscreens, oil, or lotions as a skin protector, which will maintain the overall skin texture and youth (Viola and Viola, 2009).

Furthermore, olive extracts from olive byproducts also have remarkable moisturizing and hydrating components, reducing stiffness, thanks to its rich nature of squalene, oleuropein, and several minerals. Other than helping skin aging and protection, olive oil and extracts obtained from seeds and leaves are known to be antimicrobial and anti-inflammatory, helping skin to be smoother, cleaner, and less of imperfections. Therefore olive oil and other extracts are suitable to be added to skin cleaners, sebum regulators, and creams. (Rodrigues, Pimentel and Oliveira, 2015).

On the other hand, olive oil is also commonly used in hair care products, mostly in the form of shampoos, hair conditioners, masks, and other products. The moisturizing and smoothening effects of olive extracts are also used for retaining hair health. In addition to that, olive oil and pomace are also effective on hair growth, which makes them appropriate as a biomaterial in hair care products (Rasouli, Mazinani, and Haghbeen, 2021).

3.1.1.10.2. Production and Processing of Olive

Several extraction alternatives are used in the extraction process of olive oil and other bio-compounds from leaves, stems, and mill water wastes. The process starts with washing, grinding, and pressing relevant parts of the olive, which is then followed by extraction. There are various conventional extraction methods such as enzyme, infrared, and microwave-assisted extraction, which need the use of several chemical processes. Other than that, there are greener technologies such as ultrasound-assisted extraction, subcritical water extraction, and supercritical fluid extraction. These methods are preferred more since they are more effective in terms of valuable component extraction, less time-consuming, and do not require chemical solvents. Plus, these greener methods also need lower temperatures compared to conventional methods, decreasing the risk of damaging the material and its active substances (Otero et al., 2021). Therefore, these emerging green methods are more suitable for companies who aim to transform their processes in addition to using biomaterials.

3.1.1.10.3. Pros and Cons of Olive in Cosmetics

Olive is a fruit that is harvested abundantly and at relatively low costs, which makes it an affordable, healthy, and natural biomaterial for industry uses (Cádiz-Gurrea et al, 2021). On the other hand, a high amount of waste is created in olive oil processing and these leftovers are rich in antioxidants, vitamins, fatty acids, and bio-compounds, which creates a huge opportunity for appreciating wastes and obtaining more sustainable processes by recycling. Moreover, there are many ways to obtain olive oil and other extracts in an environmentally conscious and

sustainable way, which makes the general process of olive-based cosmetics production greener (Rodrigues, Pimentel, and Oliveira, 2015). As mentioned, since olive oil has been used as a safe and traditional beauty ingredient, consumers trust the olive as a material in cosmetics.

While olive oil is considered a safe and trusted ingredient, there is less research about olive waste products in cosmetics. Since there are fewer tests are conducted in terms of the ideal concentrations, efficacy, bioactivity levels, irritation, and allergic reactions, some concerns are present about the material extraction from seeds, leaves, and wastewater (El and Karakaya, 2009; Rodrigues, Alves, and Oliveira, 2023).

3.1.1.10.4. Companies Producing and Using Olive in Products

Olivella is an American brand that produces and serves both extra virgin olive oil as a material and the personal care products produced including this oil. The product portfolio of the brand is very large and includes soaps, body and face creams, gels, and hair products. The company also reuses water and aims to cut down carbon emissions and be completely green (Olivella®, 2023). Herbolive is another company, based in Greece, which sells organic and olive-based cosmetics and personal care products including hand, body, and face creams, shower gels, lip balms, anti-aging products, and oils (The Olive Tree, 2023). Olive Oil Skincare Company is an Australian brand that produces extra virgin olive oil and skincare, haircare, and beauty products produced with their oil. The company also eliminates several chemicals such as paraben, SLS, and artificial fragrances and only uses natural materials in its products (The Olive Oil Skincare Company ©, 2023). Idea Toscana is an Italian company that sells personal care products including extra virgin olive oil from Toscana. The company has a wide portfolio of haircare, skincare, lip care, and face care products. The company also uses 100% natural origin materials and practices cruelty-free production (Idea Toscana ©, 2023).

3.1.1.11. Pineapple

3.1.1.11.1. Pineapple Plant in Cosmetics

Pineapple is one of the most valuable tropical fruits that is mostly cultivated in Latin American, African, and Asian countries which have tropical and relatively hot climates. The fruit is known to have many benefits to health thanks to its high nutrients including several types of vitamins and minerals. While it is mainly considered a food source, the edible part of pineapple only constitutes around 50-60% of the fruit, which led to the other half being mentioned as waste, including peels, roots, seeds, and leaves (Hikal et al., 2021). The importance of waste

management is increasing each day and fruits and their leftovers become a very valuable source of biomaterials. The available waste of pineapple becomes a good source that can be used in different fields since the leftover parts of the fruit also carry many biological substances that can be extracted and applied as a bio-based material. Being natural, non-toxic, and rich in various bio-compounds, pineapple, and its residues come forward as precious biomaterials that are increasingly added inside cosmetics and care products (Freitas et al., 2014).

Pineapple is known to be a fruit that is rich in bromelain, a mixture of enzymes that has many potential benefits on health. Bromelain has been a valuable source in the pharmaceutical and cosmetics industry, having a significant effect on healing wounds, and relieving pain and swelling. The fact that pineapple waste is also rich in bromelain, pineapple residues gained huge importance for the producers who are seeking a sustainable and beneficial biomaterial for their products. In addition to the medical benefits, bromelain is found to be very useful in cosmetics and personal care industries, being rich in antioxidants, and having anti-inflammatory and a variety of healing effects (Ketnawa, Chaiwut and Rawdkuen, 2011).

Bromelain extracted from the pineapple stands out as antimicrobial and anti-inflammatory competent and is found to be effective in acne healing, unclogging pores, and balancing the oil on the face. Moreover, past research also found that these antimicrobial capabilities of bromelain are also effective in fighting wrinkles and skin aging. These exfoliation benefits come from the capacity of bromelain enzymes that clean the dead skin cells and support the production of new young skin cells. (Ramli, Aznan and Illias, 2017). Thus, bromelain is an appropriate compound that can be applied to cosmetic products such as peeling masks, lotions, and cleansing tonics or water. In addition, to exfoliation, the bromelain content in pineapple is also helpful in terms of moisturizing and softening dry skin. These hydrating effects make pineapple also a usable source as a moisturizer in creams and lotions (Packianathan and Kandasamy, 2011).

Some of the past research has also determined that the healing and swelling-reducing properties of bromelain can also help reduce cellulite problems in women, which are caused by excessive and uneven accumulation of water and fat cells. Anti-inflammatory and dissolving benefits of bromelain can support the protection and decrease of cellulite and make pineapple applicable to the products that claim themselves as anti-cellulite (Spir et al., 2015).

Pineapple is also known to be a good source of polyphenols in its peels, which are plant metabolites that have many benefits, such as anti-microbial, antioxidant, anti-allergenic anti-

inflammatory functions. These functions of polyphenols promoted the use of polyphenols in cosmetics to support UV protection, fight against skin aging, hydration decrease irritations and imperfections on the skin (Li et al., 2014). Hence, being a biological and rich source of polyphenols, pineapple emerges as a suitable biological material that can be and is used widely in cosmetic products.

Another important aspect of pineapple is that it is found to be beneficial in terms of skin whitening with its anti-browning effects. Although this fact of pineapple extracts has not been explored widely in literature, there are few types of research on this specific area and a US patent about the anti-browning and skin-whitening properties of the pineapple ingredients (Zheng et al., 2010). These findings may support that chemical bio compounds extracted from pineapple peels can be used as whitening agents in cosmetics such as face creams or masks.

3.1.1.11.2. Production and Process of Pineapple

Several conventional and chemical methods are used to extract the valuable compounds from pineapple to be used in other products. Soxhlet extraction and hydrodistillation are the most popular conventional methods that are used to extract bioactive compounds, but these methods are not highly appreciated due to the loss of value caused by using a high level of chemicals and heat. Moreover, these methods are still high-cost and not environmentally friendly. Thus, more innovative processing methods have been searched recently, and more novel methods to obtain bioactive compounds from pineapple are listed as ultrasound-assisted extraction (UAE), hydrothermal extraction, wet grinding, microwave-assisted extraction, enzymatic extraction and extraction with ethanol and methanol (Rico et al., 2020).

3.1.1.11.3. Pros and Cons of Pineapple in Cosmetics

Every part of pineapple contains high nutrients and valuable bio-compounds. In the field of sustainability, pineapple has become a pioneer material since even its leftovers such as peel, seeds, and core contain quality bio-substances, some of them even more than the fruit itself. Thus, pineapple residues can conveniently be used in products in cosmetics and care. Moreover, pineapple leftovers are already used in these industries in the form of fragrances and aromas, obtained by essential oil extraction from the pineapple (Hikal et al., 2022). On the other hand, pineapple is a non-toxic, highly biodegradable, and low-cost biomaterial, so its use is very convenient for companies who are looking for more environmentally and economically sustainable material alternatives. Plus, from the past research, it’s proven that pineapple has a high variety of health benefits due to having antimicrobial, anti-inflammatory, anti-cancer, and

anti-aging properties. The drawbacks of this content are mainly due to the existence of few sources about pineapple addition to cosmetic products. While it is known that there are a large number of pineapple-added products in the market, there are not many academic sources in the literature that list pineapple as the pioneer material of the health benefits or replacement of non-sustainable materials. Also, chemical processes that are mainly used for obtaining extractions are thought to be hazardous and cause a decrease in the nutritional value of bio-compounds, thus not very sustainable and healthy as a whole (Rico et al., 2020).

3.1.1.11.4. Companies Producing and Using Pineapple in Products

Quality Plus is a Thai biotechnology company that tests and produces sustainable biomaterials, mainly fruits, and plants, and sells or applies them to cosmetics and personal care products. Pineapple is one of the materials they are working on, especially for its bromelain content. The company is conducting several tests with different universities and research centers about pineapple extractions and produces the bromelain extract for cosmetics with the claim of acne treatment, skin-whitening, and exfoliating benefits (Quality Plus Biomedtech Co., Ltd., 2023).

Garnier is one the biggest cosmetics companies in the world, that uses pineapple-embedded hair care products such as shampoo, conditioner, and mask with the name of Pineapple & Amla Hair Food. These hair products are said to be rich in vitamins C, A, and E, helping hair to be healthier, grow better, and become smoother. Additionally, Garnier also markets pineapple-based face serums and masks, supported by bromelain. These face care products claim that they exfoliate, brighten the skin, and reduce imperfections thanks to the beneficial bio compounds obtained by pineapple (© Garnier, 2023). Glow Recipe is an American cosmetics company providing fruit-based sustainable products that are also cruelty-free. The company has recently launched a serum named Pineapple-C Bright Serum, which is specially produced for making skin glow and shine better, with the help of vitamins, bromelain, and alpha hydroxyl acids accompanying the pineapple fragrances. The serum is specially targeted at customers who are looking for a less chemical-based and cruelty-free product that helps to control hyperpigmentation, skin imperfections, and dullness (Hoshikawa, 2019).

Other smaller-scale brands serving pineapple-infused cosmetics products can be listed as Herbivore (Brighten Pineapple Enzyme + Gemstone Instant Glow Mask), Too Faced (Pineapple Glow Face Mask), Pacifica (Pineapple Bubbles Clarifying Bubble Mask), Shaffali (Pineapple & Peppermint Exfoliant), Juice Beauty (Exfoliating Cleanser) and many more. All

of these products take taking benefits of pineapples' exfoliating, cleansing, and moisturizing properties, in addition to the appealing aromas and fragrances the fruit has (Prinzivalli, 2019).

3.1.1.12. Tea

3.1.1.12.1. Tea Plant in Cosmetics Field

Tea is one of the most popular plants that is consumed in the form of beverage by many people, thanks to its soft texture, pleasant aromas, and several health benefits. There are many different types of tea, ranging from black to green, and many different fruits and flowers. Tea is a plant that is full of antioxidants, polyphenols, anti-carcinogenic elements, vitamins, and minerals, thus is consumed by many people as a functional treatment for different health conditions. It is known to be a plant that is supportive of to fight against viral infections, fatigue, cardiovascular diseases, weight loss, and even cancers (Sinija and Mishra, 2008). Even though it is most commonly used as a beverage, tea has also been used as a bio-ingredient for many different type of products since very past years, cosmetics and personal care products are one of these types of products that contains tea extracts commonly since tea is beneficial for skin and hair health from many perspectives (Chaikul et al., 2020).

First of all, tea is found to be effective in protecting the skin barrier against ultraviolet lights such as UVA and UVB, thus maintaining skin elasticity and moisture, and preventing solar damage and aging of the skin. Black, green, white tea, and tea tree oil have been tested in past research and found effective in maintaining skin texture and health (Camouse et al., 2009). Also, green tea is beneficial for preventing skin pigmentation and thus helps to reach a more even skin tone (Chiu et al., 2005). Therefore, tea extracts are useful in sunscreens, skin protection creams, and anti-aging or anti-wrinkle skin care products.

Green and black tea extracts are also found to have anti-inflammatory and antibacterial capabilities that heal inflammations, damage, and wounds, fight malicious tumors, control the sebum level, and protect the hair follicles from sun damage and radiation (Feng et al., 2021; Hsu, 2005). Furthermore, according to the research of Katiyar (2011), topical application of green tea can be effective in preventing melanoma, which is a type of skin cancer, with the strong protection capabilities of green tea polyphenols and anti-carcinogens, and help repair damaged and cancerous DNA and skin cells. Tea tree oil is also reported to be effective in reducing acne and sebum on topical use (Hammer, 2015). All these researches support that tea is a crucial biomaterial for skin care products with many benefits.

Tea is a plant that is rich in caffeine. Caffeine has been proven as a substance that is effective in fighting the disarray and unwilling appearance of cellulite and fat cells. The presence of caffeine is the reason why tea extracts are used as a material in anti-cellulite products. Tea polyphenols are effective in reducing fat cells and edema in a few researches, but still, there is a strong need for further research in this area (Koch et al., 2019).

In addition to the skin benefits, tea is also used in hair care products to help several conditions on the scalp. First of all, the sun protection effect of tea also helps to maintain hair health and texture. Besides, in several researches, it has been identified that tea extracts may also support hair growth and thickness. However, there is research on this area with human subjects (Kwon et al., 2007; Esfandiari and Kelly, 2005). On the other hand, tea extracts and oil are commonly used as a sebum-balancing agent in hair care to help clean and control excess amounts of oil on the scalp. Tea constituents are also used as moisturizers and smoothening agents for hair care, eliminating the roughness of the hair and in the end giving hair a more healthy appearance. Plus, it is known as a preventive agent against dandruff. Tea tree oil is also added to hair care products as a natural protectant for lice. (Koch et al., 2019; Hardman and Priest, 1999).

3.1.1.12.2. Production and Processing of Tea

Tea tree oil is mostly extracted from tree woods, with manual and non-chemical methods. On the other hand, to obtain beneficial compounds from tea, organic solvents, microwave and ultrasound-assisted extraction, filtration, chromatography, drying, and distillation methods are used, which are not completely chemical-free, healthy and sustainable (Vuong et al., 2010). There is a lack of clear research on the tea-based material extraction methods for use in cosmetics and personal care, so the assumptions mentioned are the facts taken from experiments used in this literature review.

3.1.1.12.3. Pros and Cons of Tea in Cosmetics

Tea is a plant that is known and trusted by society, thanks to the proven effects of health benefits for many years. Additionally, tea production and consumption creates large amounts of waste which is full of antioxidants and polyphenols. So basically, leftovers of tea are an available material that to be added to cosmetics and can be eliminated from nature (Zahra et al., 2022). In summary, tea is an available and low-cost biomaterial with various proven benefits and trust, which is conveniently applicable to cosmetics and personal care.

On the other hand, the condition of tea tree oil has been discussed in several researches in terms of toxicity. These researchers concluded that topical application of tea tree oil is safe, in contrast to oral use, when it is not used excessively (Carson, Riley, and Cookson, 1998). There are several types of research are going on in the literature to identify the possible allergic reactions and irritation due to the use of tea tree oil (Southwell, Freeman, and Rubel, 1997). One of the other possible disadvantages of tea use can be identified as the extraction of needed substances for products, which are mostly chemical-based, preventing the whole process from becoming green, as mentioned in the section above.

3.1.1.12.4. Companies Producing and Using Tea in Products

Teology is an Italian cosmetic and personal care brand that sells tea-infused natural products. The company uses recyclable raw materials and packaging to decrease CO2 emissions and aims to adapt to a completely sustainable business model. The product portfolio of the company ranges from tea-based oils, masks, shampoos, anti-aging and moisturizing creams, serums, lip balms, perfumes, and many more different cosmetics and care products (Teology ©, 2023). Earth to Skin is another brand that specializes in natural cosmetics products, and the brand serves many green tea-infused products under the brand name of Tea Time, such as face cleansers, night creams, anti-aging creams, and masks (Earth to Skin, 2023). Tea Shop is a Spanish e-commerce brand that sells different types of teas, accessories, and personal care products that are tea-based. The company sells tea-infused products under the brand name Miracle Beauty, which contain hand and body creams, sprays, facial serums, and micellar water (Tea Shop, 2023). Lotus Botanicals is another India-based natural cosmetics brand that sells tea-based creams, moisturizers, night gels, and face serums (Lotus Botanicals ©, 2023). Neogen, TonyMoly, Kumiko, Fresh, Kiehl's, L'Occitane, Elisabeth Arden, Mario Badescu, Byroe, Origins, and Tree of Life are other natural and high-end cosmetics brands that sell different kinds of tea extract-infused products (Basu, 2022; Mansi, 2021).

3.1.2. Animal-Based Biomaterials in Cosmetic Products

3.1.2.1. Chitin

3.1.2.1.1. Chitin Material in Cosmetics Field

While the importance of bio-based materials increasing each day, they are mostly recognized as plant-based materials. On the contrary, many other biologic organisms such as animals are becoming important sources of biomaterials that can be replaced with chemicals. Chitosan,

which is obtained from the material chitin, is a multifunctional biopolymer that is used in many different types of products in the personal care and cosmetics industries. Numerous benefits and importance of chitosan are increasing each day, and thanks to its abundance, it is becoming a pioneer in the animal-based biomaterial that is used for more sustainable and healthier products (Morin-Crini et al., 2019). Chitin is a biological material that can be obtained from insect shells and crustaceans like crabs, shrimps, lobsters, and scales of fish. Chitin is considered one of the most abundantly found biological polysaccharides in the world, due to the existence of chitin in many various living organisms (Triunfo et al., 2021).

Chitosan is the organic biopolymer that is derived and deacetylated from chitin, which is the raw material form. The increasing importance of environmental and health concerns has put people in search of more innocent and healthy bio-based products, and chitosan is becoming one of the primary animal-based biomaterials that are safely used in personal care and cosmetic products. Its various benefits and organic nature are making both consumers and producers more aware and willing to use products that contain chitin and chitosan. A variety of conducted research and experiments concluded that chitosan can be used in many different types of products in the personal care and cosmetics industry, including skin care, hair care, make-up, dental care, toiletries, hygiene, oral care, and cosmeceuticals. To this date, chitosan is used in various types of products such as moisturizers, shampoo, mascara, nail polish, hair spray, soap, hair dye, and toothpaste (Guzmán, Ortega, and Rubio, 2022).

One of the most known benefits of chitosan in cosmetics is the moisturizing effect. According to past research, carboxymethyl chitosan, which is the form of chitosan that is soluble in water and has superior water-holding capacity, is used commonly as a moisturizing agent in skin care products. Carboxymethyl chitosan-based products have also shown protective effects on irritations and dryness caused by several chemical detergents. Having moisturize-retention and absorption capacity, chitosan is commonly used in many lotions, creams, and conditioners to maintain the smoothness and health of the skin (Jimtaisong and Saewan, 2014).

Other than skincare, chitosan is also used in various hair care products. Almost all type of hair products such as shampoos, dyes, conditioners, hair sprays, and heat-protection products contains chitosan and derivatives. In these products, chitosan works as a protection and thickening agent. In past research, it has been found that when combined with collagen and hyaluronic acid, chitosan supports hair strength and decreases hair fall, while protecting the natural texture of the hair, making it softer and thicker (Sionkowska et al., 2017). Recently, the use of chitosan has increased in lip care and nail care products, due to these beneficial

compounds in chitosan helping healing of cracks, wounds, and dryness (Dhillon et al., 2013). Moreover, the healing benefits of chitosan are not limited to lips and nails. Through past experiments, it has been proven that chitosan is also effective in acne healing and balancing the oiliness of the skin by lowering the sebum. Due to having antibacterial and treating nature, chitosan is broadly used in skin cleansing gels, serums, and tonics (Guzmán, Ortega, and Rubio, 2022).

Skin aging and UV protection are the other very important benefits of chitosan compounds in personal care products. Previous tests showed that chitosan-embedded products support the protection of skin from harmful radioactive lights and improve the condition of the skin in case of burns and damage due to UV exposure. Furthermore, skin aging impacts such as wrinkles, roughness, and hyperpigmentation caused by UV radiations can be diminished by chitosan-containing products. Eventually, these potential benefits are willingly used by cosmetics companies that are serving products such as sunscreen lotions and anti-aging creams or serums (Kong et al., 2018).

In addition to all the benefits mentioned, chitosan also works as an emollient, humectant, surfactant, emulsifier, stabilizer, and viscosity agent in cosmetics and personal care products (Aranaz et al., 2018). All these functions of chitosan make it a very valuable biomaterial in these industries and its application window is increasing continuously, especially for the producers looking for sustainable and healthier material options.

3.1.2.1.2. Production and Process of Chitin

Chitosan can be extracted by biological methods or chemical methods to be used in products. The chemical process includes deproteinization and demineralization with alkaline and hydrochloric acid. These extractions depend on the products chitin is prepared for and the animal from the chitin is obtained. In the end, chitin is obtained in the form of powder to be added to products. Some powder may need extra treatments such as bleaching through other chemicals. On the other hand, the biological extraction of chitosan is preferable from the green process perspective. The bio-extraction process is mentioned to be healthier and more ecologic compared to chemical extraction. Bio extraction process includes bacterial fermentation and enzymatic hydrolysis of the chitin obtained by shells. Biologic extraction is more beneficial in terms of maintaining the nutritional value of the chitin and passing it to the products (Casadidio et al., 2019).

3.1.2.1.3. Pros and Cons of Chitin in Cosmetics

Chitin can be obtained by many different types of living organisms, mainly from marine creatures and fungi. One of the most specific advantages of chitosan use is its abundance in nature. Furthermore, since it is obtained from biological organisms, it is a highly biocompatible and biodegradable material that can be applied to many industries. Being non-toxic, it is also becoming more attractive in the eyes of customers and producers. Finally, bio extraction of chitin is possible, which makes the production process of chitosan-based materials completely green, supporting sustainable life cycles (Kulka and Sionkowska, 2023). Disadvantage of the chitosan usage in cosmetics is mostly due to the higher costs of obtaining pure material compared to petroleum-based substitutes. Another problem is, that the optimal level of its benefits is not reached from products, mainly due to the limited experiments and research on the application of compounds. Additionally, the chemical extraction method of the chitosan cannot be considered fully sustainable due to the use of large amounts of chemicals and heat. On the other hand, the biological method is almost fully green, only being more time-consuming and costly (Aranaz et al., 2021).

3.1.2.1.4. Companies Producing and Using Chitin

Chitin-based products are increasingly used in many innovative companies all around the world. Primex is an Icelandic marine biotech company and is a pioneer in pure chitosan products. With their brands named Chitoclear and Chitocare, the company serves a wider range of cosmetics and care products containing chitosan powder (Primex EHF, 2023). Many companies are providing chemicals or cosmetic-grade chitosan ingredients to the companies. These providers of chitosan and similar compounds to other organizations can be exemplified as Chitinor AS, Clariant, Ovensa Inc., Vink Chemicals, Rita Corporation, and more (Guzmán, Ortega, and Rubio, 2022).

An American company named Kristen Ess Hair provides hair care products such as cleansing and restoring shampoos, hair masks, and conditioners that contain chitosan. The well-known company P&G sells hair styling gels with chitosan under the Herbal Essences brand. Briogeo, Aussie, Babington, Hair Food, Tigi, and Vernon Francis can be listed as other small-scale companies that provide chitosan-containing hair care products ranging from shampoos to serums (EWG's Skin Deep®, 2023). Unilever sells body lotions under the brand name St. Yves, which uses chitosan as a moisturizing agent. Murad LLC is another company that sells chitosan-containing creams for anti-aging and moisturizing benefits (EWG's Skin Deep®, 2023).

3.1.2.2. Honey

3.1.2.2.1. Honey Material in Cosmetics Field

Along with other animal-based biomaterials, honey takes a strong position. Bees are one of the primary sources of honey, which has been used extensively for very past centuries as a skin treatment agent. Looking through the past decades, it has been seen that honey, mixed with other natural sources, is used as a homemade treatment for moisturizing skin, thickening the hair, cleansing the skin and even healing fungal infections and wounds (Burlando and Cornara, 2013). Since the importance of bio-based cosmetics is rising, honey has become even more important due to its natural origins and many benefits.

Compared to other animal-based biomaterials, honey is known and used more widely in cosmetics and personal care products. In the market, it is seen that many hair care, skin care, and even medicines contain honey inside, claiming to benefit many simple health issues. In literature, honey is known to be used as a skin cleanser, moisturizer, acne healer, hair softener, and thickener, and a general skin soothing ingredient. That's why it is commonly used in shampoos, conditioners, body lotions, face creams, lip balms, masks, and even as a fragrance due to its pleasant smell and texture (Kumar, Agrawal, and Hajam, 2022).

The vast use of honey in cosmetics and personal sectors is due to its high nutritional value, different health benefits, and texture which makes it appropriate to be implemented in these products easily. Honey is known to be a natural humectant, meaning it is very effective on moisturizing. That's the reason it is widely used in hair and skin products as a moisturizing agent (Dixit, 2005). In addition to being a strong moisturizer, honey has other important properties such as being antimicrobial, anti-inflammatory, anti-cancer, and antioxidant activities. Moreover, past research has also found that honey is effective in wound healing such as burns and cuts, and skin renewal after irritations and damage (Pashte, Pashte, and Said, 2020).

One of the most promising benefits of honey is that is safely usable in acne treatment thanks to its antimicrobial, anti-inflammatory, and antibacterial properties. Honey is found to be effective in fighting the infections acne carries, eliminating acne, and renewing the tissue in the specific area. That's the reason why honey has become a valuable biomaterial to be used in face and body creams, masks, and cleansers. In addition to that, honey is found to be effective in UV protection, so it is also used as a protective and healing agent in sunscreens, after-sun products, and hair lotions to help with damage. (Hadi, Omar and Awadh, 2016). Another appealing

benefit of honey in cosmetics is that helps reduce wrinkles and prevent skin aging. This is due to the benefit of bioactive compounds that help honey to protect skin elasticity and juvenility (Pavlacková et al., 2020). Finally, honey application in lip balms has been tried in many research since lips are one of the most vulnerable parts of the skin and honey has healing and moisturizing benefits for cracks and wounds. These researchers also concluded that honey is a very appropriate and healthier ingredient that can be used in lip products to soften, heal, and give a pleasant feel and smell to the lips (Yusof et al., 2018). All these beneficial properties and their nature make honey a suitable bio-ingredient for cosmetics and personal care.

3.1.2.2.2. Production and Process of Honey

Compared to other animal-based biomaterials, honey needs less kind of processing, which makes it a more green and sustainable source. Honey is mostly processed by heat treatments before it is transformed into material use. These heat treatments differ depending on the area of use. The main processing methods of honey can be listed as microwave and ultrasound heating, which is followed by filtration, straining, and cooling. These processes are needed for honey to be separated from its particles, for yeast elimination, and to prevent spoilage of beneficial compounds. Heating is a very important step in honey processing since the temperature and the method of heating affect the moisturizing capacity of honey. That's why it needs to be arranged well depending on the area of use (Subramanian, Hebbar, and Rastogi, 2007).

3.1.2.2.3. Pros and Cons of Honey in Cosmetics

As mentioned, honey has a lot of different benefits on health, skin, and hair, which makes it very efficient to be used in cosmetics and personal care. Furthermore, it has been used for decades as a traditional medicine, which makes it a trusted ingredient in the eyes of many, hence potential market for honey-based products is significant. Past research also confirms these ideas since a high proportion of participants indicates that they are comfortable buying products that include honey (Diaz, Rivera, and Huerta, 2018). Another advantage of honey use it needs no or little processing while being put inside the products, which makes it a greener material. It is known that honey is even used in raw form at home to treat specific issues, so it is convenient and sustainable (Burlando and Cornara, 2013).

Other than positives there are some possible negative aspects of honey use in products may occur. One of these aspects is honey being allergic to some people. Thus, honey-based products may not be appropriate for everyone. Additionally, some type of honey is known to be toxic, so, the choice of honey and their proportions should be adjusted carefully after conducting

several experiments (Kumar, Agrawal and Hajam, 2022). On the other hand, some customers are not willing to purchase products that have animal-based ingredients, claiming it is not green and ethical. Since honey and derivatives are mostly obtained from bees, they do not attract these segments of customers (Cervellon and Carey, 2011).

3.1.2.2.4. Companies Producing and Using Honey

Bee Cosmetics is a UK-based skincare brand that produces and sells bee-based products ranging from creams, skin cleansers, serums, balms, and scrubs. The company is also the one that formulates the products including honey, propolis, and beeswax. They aim to decrease their impact by transforming their raw materials and processes and promoting a natural and healthier lifestyle (Bee Cosmetics, 2023). Panier des Sens is a French company, selling various types of honey-based body care products to support their sustainable goals along with their other biomaterial-based products, bulk sales, and recyclable packaged products (Panier des Sens, 2023). Farmacy is a US-based cosmetics brand that serves many different types of honey-based moisturizers, serums, balms, and body and face care products claiming to help people with their clean and cruelty-free products (Farmacy Beauty, 2023).

Other than these sustainable brands, larger and high-end brands such as Lancôme, L'Oréal, Guerlain, Sunday Riley, and Laura Mercier also markets honey-infused products such as creams, serums, eye gels, and oils as nature-based skincare options (Leong, 2022; Shannon, 2022).

3.1.2.3. Milk

3.1.2.3.1. Milk Material in Cosmetics Field

Milk has been a valuable source of nutrition for millions at every age for many centuries. Milk is very abundantly produced animal based on natural and biological material, which can be obtained from different types of land animals including cows, sheep, donkeys, camels, goats, horses, and many others (Cristiano and Guagni, 2022). Due to its high volume of protein, healthy fats, vitamins, and minerals, milk is consumed by almost everyone in their daily lives. Its high content of protein including casein, lactoferrin, immunoglobulins, lysozyme, and others, leads to milk being a source which is full of antioxidants, and becoming antibacterial, anti-inflammatory, antiviral, anticancer, antifungal, regenerative, and supportive of growth function (Kazimierska and Kalinowska-Lis, 2021). These benefits of milk created many opportunities for the use of milk in other industries such as cosmetics and personal care, along

with dietary supplementation. Milk has been used as a natural traditional medicinal and beauty material for many centuries, and its presence in cosmetic products such as creams, gels, cleansing milk, and tonics is increasing significantly (Cosentino et al., 2018).

One of the most significant benefits of milk on the skin is its moisturizing effect. Milk is capable of hydrating and cleansing the skin, owing to its rich nature of antioxidants, and makes the skin more smooth, shiny, and soft. Donkey milk and goat milk are two of these kinds of milk that are commonly used in face and body creams, cleansing milk, and toners for these moisturizing benefits (Bhardwaj et al., 2020; Ribeiro and Ribeiro, 2010).

In addition to being a good moisturizer, goat milk is also supportive of wound healing and maintaining skin elasticity, thanks to its composition of zinc, and vitamins A and C. Moreover, active bio-compounds of milk also help slow the skin aging rhythm (Voloshyna et al., 2021). Along with goat milk, camel milk is also effective in slowing down the skin aging process by decreasing the wrinkle forming, and maintaining the smoothness, moisture, calmness, and thickness of the skin, owing to its rich nature of vitamins and alpha-hydroxyl acids.

As milk has antimicrobial, anti-inflammatory properties and zinc, vitamins, and lactoferrin, it has remarkable effects on balancing the sebum level on the skin, preventing and healing acne, blackheads, and other skin lesions, and maintaining overall skin health when it is applied topically (Chan et al., 2017; Kazimierska and Kalinowska-Lis, 2021). These findings support that milk is a useful biomaterial for anti-acne, anti-imperfection, and skin cleansing products.

Milk also has many potential benefits as a bio-ingredient that can be used safely in hair care products other than skincare. Casein derivatives lactoglobulin, yogurt, whey, and other milk protein derivatives are reported as effective protein compounds that are used as hair conditioning agents, which help maintain hair texture and health (Burnett et al., 2022).

3.1.2.3.2. Production and Processing of Milk

Milk is obtained from different type of animals such as cattle, goat, camel, horse, sheep, and other land animals, and the form of milk to be included in cosmetics depend on the product type. Milk can be added to cosmetic products in several forms which can be listed as milk itself, hydrolyzed milk and its protein, hydrolyzed whey protein, lac, milk extract, milk powder, and others (Prokopowicz and Różycki, 2017, p. 449). Hydrolyzing proteins is one of the most common methods to infuse milk and its bio-compounds into cosmetics. For the required proteins to be active and effective in cosmetics, they should be soluble in the water and that’s

the reason why hydrolysis should be performed on milk, which is a chemical process to break the bonds of protein molecules and decrease their size. In this way, proteins and other bio-compounds become effective for maintaining skin and hair health (Secchi, 2008). On the other hand, the fermentation of skimmed or unskimmed milk by enzymes is another method to activate valuable compounds such as pepsin, pancreatin, and other bacteria for cosmetic use. Additionally, milk can also be included in cosmetic products in the forms of yogurt, milk powder, and whey, which may be obtained by both chemical and mechanical methods (Giddey et al., 1991).

3.1.2.3.3. Pros and Cons of Milk in Cosmetics

In cosmetic applications, milk has various advantages as a biomaterial. First of all, it has been used as a safe food source and traditional medicinal ingredient for centuries, accepted by millions of people as a safe and natural material. Milk is produced by many different animals and it is abundant in terms of amount, and using milk in cosmetics is a good way to handle possible dairy waste (Audic, Chaufer, and Daufin, 2003). As mentioned in the previous section, milk can be added to cosmetics in diverse forms, which can be obtained by less chemical or completely mechanical methods which can be considered greener. And since milk is beneficial for health and skin from many different perspectives and helpful for several conditions, it is a very suitable material as a cosmetic ingredient. On the other hand, milk-derived cosmetic ingredient production processes such as extraction tend to be costly and require time to reach optimum benefit points. In addition to these, the storage time of the milk components is dependent on the preservative agents, which may mean having a short time to keep the ingredient active and beneficial. That's why the ideal composition, storage requirements, and chemical agents to obtain compounds should be arranged for optimal conditions (Giddey et al., 1991).

3.1.2.3.4. Companies Producing and Using Milk

Although milk and its proteins have significant benefits for the skin, recently more plant-based milk such as oat milk started to take over the market of milk-based cosmetics, mostly due to the shift in consumer expectations and sensitivity towards animal-based ingredients (Coates, 2022). However, there are still plenty of cosmetics brands that use milk and its derivatives in their products. Nurst is a small startup company with the purpose of sustainability which produces and sells cow milk-based creams and moisturizers in a cruelty-free way with natural ingredients (© Nurst, 2023). Asian Beauty Essentials is an innovative e-commerce cosmetic

and personal care brand that sells several milk-included products such as creams, lip balms, face masks, toners, eye patches, and hair products such as oils, shampoos, and creams (© Asian Beauty Essentials, 2023). Korres, Kate Somerville, MooGoo, Oskia, and Freeset are other brands that market milk-infused beauty products such as face cleansers, masks, and creams (Pearson-Smith, 2017).

Other than the mentioned cosmetic brands that sell milk-infused products, there are also milk-derived ingredient producers who supply milk, protein, and its derivatives for cosmetic use. Croda is a brand that provides cosmetics and personal care ingredients for their customers. One of the ingredients the company sells is milk extract, which is suitable for hair products, soaps, creams, sunscreens, lip care products, and facial cleansers (© Croda International Plc, 2023). Hydrolyzed milk protein is another form of milk-derivative ingredient which is sold for cosmetic use. Additionally, brands that provide hydrolyzed milk protein are listed in SpecialChem's platform such as BioOrganic Concepts, Kelisema, Aqia, and Teluca (© SpecialChem, 2023).

3.1.2.4. Silk

3.1.2.4.1. Silk Material in Cosmetics Field

Silk is a valuable material that can be extracted from different types of insects or spiders, mostly from silkworms. Silk has been preferred as a raw material in textile products for several years, and silk-based products are known to be high quality, durable, biodegradable, and water resistant, therefore very desirable for both producers and customers (Asakura, Kametani, and Suzuki, 2018). While silk is generally used as a raw material for the textile industry, in recent years its application in other industries such as biomedicine, pharmaceuticals, and cosmetics has increased. These studies concluded that silk proteins have antioxidant, anti-cancer, anti-bacterial and anti-inflammatory properties, and helped the realization of the opportunities of silk used for skin and hair benefits (Chlapanidas et al., 2013). Silk is a biological material that is also rich in valuable proteins, including sericin and fibroin. Sericin, fibroin, and hydrolyzed forms of these two proteins, silk extract, powder, and cocoon extracts are different forms of silk that are appropriate to be added into cosmetics as biomaterials (Johnson et al., 2020). Moreover, an important amount of waste is created in the process of silk-based textile products, and fibroin and sericin can be extracted from this waste to be used in other areas of application such as cosmetics, making it possible to valorize waste and support environmentally sustainable actions (Padamwar and Pawar, 2004).

Silk proteins have numerous different benefits for the skin. First of all, a protein obtained from silk such as sericin is effective as a moisturizing agent and helps maintain the hydration level of skin and hair, which makes it a suitable smoothening ingredient in skin care products such as lotions and creams (Padamwar et al., 2005). In addition to the moisturizing effect, sericin also has protective effects against harmful UV lights, maintaining skin texture and elasticity, and eventually slowing down skin aging and wrinkling. Moreover, it also helps the regeneration of the skin in the presence of dead skin cells or wounds. Therefore, silk proteins are increasingly used as anti-aging and anti-wrinkling agents in face and body creams, sunscreen products, lotions, masks, and oils (Grześkowiak and Lochynska, 2022; Tengattini et al., 2020).

As for hair care, sericin protein is useful for hair conditioning and protecting hair from being damaged. Additionally, it also acts as a moisturizer as it is skincare, which makes it appropriate for use in conditioners, shampoos, and hair creams. (Fatahian et al., 2021). Along with the use of skin and hair care products, silk proteins are also used as an ingredient in nail care products, with the benefits of protecting nails from impacts, cracks, and brittleness, and supporting the healthy growth of nails (Padamwar and Pawar, 2004). Finally, silk proteins are also used as materials in the color cosmetics group, which consists of several make-up products such as lipsticks, eyeshadows, mascaras, and nail polishes (Grześkowiak and Lochynska, 2022).

3.1.2.4.2. Production and Processing of Silk for Cosmetic Use

Silk is obtained from different types of insects or spiders, and this silk is generally used as a material for the textile industry. Sericin is the main silk protein that is extracted for cosmetic use, and that's the reason why literature mostly has extraction methods of sericin for cosmetics. Various methods of sericin extraction methods can be listed as conventional, chemical, enzymatic, and heating (Silva et al., 2022). While conventional and chemical methods, with acidic and alkaline solvents, are considered to be effective in obtaining a good amount of sericin easily and low cost, they are not considered friendly methods and they cause sericin to lose their valuable compounds which could be beneficial for biomedical and cosmetic use. The enzymatic method is considered environmentally friendly and effective, but more costly compared to others. On the other hand, heat treatment is a method that is considered both environmentally friendly, effective, and low cost, with risks of degradation of sericin and fibroin, depending on the applied heat level. Unfortunately, all of these mentioned methods have risks of damaging the benefits of sericin, except the alkaline extraction method, which can be considered as the main method in the area where sericin bio-active compounds are vital. In the case of

environmental and economic sustainability context, heat and enzymatic methods become more advantageous (Lamboni et al., 2015; Wang et al., 2019).

3.1.2.4.3. Pros and Cons of Silk in Cosmetics

Silk is a biomaterial that is produced naturally by animals. Several kinds of research supported that silk and its proteins are nontoxic and biocompatible, which implies they do not pose any health risks and that the use of silk proteins in cosmetic products is safe (Johnson et al., 2020). Additionally, silk sericin is a highly biodegradable material rich in bioactive compounds, which makes it environmentally sustainable. It is also highly soluble in water, which eases the process of adding silk proteins to cosmetics and personal care products. On the other hand, silk sericin is known to have weak mechanical strength, which makes it a sensitive and easily deformed material that may cause difficulties in the application of the material into products (Silva et al., 2022). Silk is mainly produced in Asian countries and less in European regions, and the production volume and market of the silk is not as large as other animal-derived or plant-derived biomaterials used in cosmetics. Plus, silk is considered a high-cost material compared to its substitutes, especially in the textile industry, but silk waste created from textiles become a good source for sericin extraction (Padamwar and Pawar, 2004). From that point, it is possible that using silk proteins in cosmetics may be economically questionable. In short, silk use in cosmetics is increasing, but it is still limited, even though it is a natural and safe biomaterial that has several benefits to skin health.

3.1.2.4.4. Companies Producing and Using Silk

Several small-size cosmetics brands use silk, its derivatives, and proteins in their products. This is Silk is a brand which is founded to provide silk-based products ranging from pillowcases to accessories and skincare products. Owners created the brand to provide silk-based bio textile products, then enlarged it to sell silk including skin products including facial cleansers, skin barrier boosters, and overnight oil (© ThisIsSilk, 2023). Tatcha is an American sustainable beauty brand that follows Japanese beauty and personal care routines and materials. The brand sells cosmetic products with biologic ingredients including plants, gold, and animal-based materials, and silk is one of these materials included in their products. Their silk-infused products can be listed as face creams, sunscreens, serums, primers, polishes, and silk powder (©Tatcha, LLC., 2023). Evolved by Nature is a biotech company that has the purpose of replacing hazardous chemicals and unsustainable materials and processes in the textile, therapeutics, and beauty industries. The company produces and sells activated silk material for

cosmetic use as an agent for protecting skin barrier and texture, and healing imperfections (© Evolved by Nature, 2022). Silk Therapeutics, Eighteen B, Dermalogica, Alpha-H, Peter Thomas Roth, and Dr. Dennis Gross are other brands, that can be considered high-end, and provide silk-infused for customers who desire to use biomaterial in their beauty routines (Foster and Robin, 2020).

Along with sustainable startups and high-end brands using silk in their products, there are biotech companies and silk producers that provide silk material for cosmetic uses. Sollice Biotech is a French company that provides silk materials in various forms such as silk powder, hydrolyzed silk protein, sericin, and other silk amino acids which can be applied to both skin care and hair care products for moisturizing, anti-aging, anti- perfection purposes (© Sollice Biotech, 2022). New Directions Aromatics is another natural ingredient brand that provides natural materials for cosmetics and personal care uses. The company provides silk additives such as powder, amino acids, and peptides. These materials are used as moisturizing, antioxidant, conditioner, and UV-protection agents (© New Directions Aromatics Inc., 2023).

3.1.2.5. Snail Slime

3.1.2.5.1. Snail Slime Material in Cosmetics Field

Snails are one of the animals that produce very valuable secretions such as slime and mucus, which can help several conditions related to human health, including skin texture. From very past centuries, snail-related secretions have been used as a traditional medicine, and nowadays, it is also used frequently in pharmaceutical and cosmeceutical products, replacing chemicals such as hyaluronic acid, or even plant substitutes of these chemicals (Cristiano and Guagni, 2022). Snail slime is preferred in cosmetics and pharmaceuticals because it is full of vitamins, glycolic acid, minerals, allantoin, collagen, and elastin, the components that help the skin to be protected from imperfections (Teixeira et al., 2018). Snail slime has bio-active compounds that have antioxidant, anti-inflammatory, antibacterial, regenerating, hydrating, and wound healing effects that proves snail slime is an important natural and healthy biomaterial that can maintain skin health and replace harmful artificial substances that are used in skin and hair care products (Ricci et al., 2023).

First of all, snail slime consists of ingredients that help the skin to keep its hydration, and in the case of skin dryness, it moisturizes skin and keeps the texture healthy. Snail slime has bioactive compounds that protect the skin barrier and heal the cracks and wounds of the skin, helping renew the skin by replacing it with damaged or dead cells (Dhiman and Pant, 2021). This

finding supports the use of snail slime in body creams and lotions, and even in lipsticks, mostly for products with moisturizing purposes. Moreover, this moisturizing and soothing effect is also valid for hair texture, so snail slime use in hair care products such as shampoos and hair conditioners is also appropriate (Laneri et al., 2019).

Along with the mentioned exfoliation capabilities, snail slime also fights with acne, blemishes, and enlarged pores, supporting the idea of adding the slime into the purifying and peeling gels, masks, and cleansers as a biomaterial (Alogna, 2017; Vargala et al., 2023). Furthermore, snail secretions are also claimed to be effective in reducing the cellulite tissue and stretch marks on the body, protecting the hydration level of the skin, and fighting wounds and inflammation (Fatima et al., 2020; Cristiano and Guagni, 2022)

Past researchers have also found that snail secretions are also effective for protecting skin from hazardous UV lights, protecting skin pigmentation, and reducing the photoaging effects, which in the end slow down the skin-aging process (Juhasz, Levin, and Marmur, 2017; Afandi and Sahudin, 2022). These research findings support the use of snail secretions in sunscreen and anti-aging creams, lotions, oils, and other products in the cosmetics range.

3.1.2.5.2. Production and Processing of Snail Slime

The main concern in the animal-derivative cosmetic material market is the ethical concerns towards animal lives and the possibility of negative health effects. Even though there are processes that may endanger animal lives, there are sustainable methods that are certified and safe for both parties (Chatterjee et al., 2022). There are various cruelty-free methods to extract snail secretion from animals without harming their biological and daily activities. The most common extraction method to obtain slime and mucus is the low voltage electrification method which stimulates snails to produce secretion. On another method, chemical stimulators such as sodium chloride are used to tease the snails to leave their mucus. After obtaining secretion with these methods, filtration and solvent methods are used to prepare the material to be integrated into products (Wargala et al., 2023). Extraction of the slime from animals can also obtained with special washing, sanitizing, and extraction machines without harming the snails (Ricci et al., 2023; Di Filippo et al., 2022).

3.1.2.5.3. Pros and Cons of Snail Slime in Cosmetics

Snail slime is an animal-derived biomaterial that can be easily and abundantly found in nature, so it is subject to some ethical concerns regarding welfare towards endangered animals and

risks of cruelty. So, there are groups of people who reject the use of animal-derived materials, which decreases the market for animal-derived biomaterials and their possible use, leading to several certifications needed for the products, which requires extra spending (Chatterjee et al., 2022). There are various methods to get snail slime and mucus without harming animals, so it is possible to obtain the material in sustainable ways. Snail secretion has been used traditionally as a safe ingredient that helps different health conditions at once, and several researchers supported this idea with experiments, tests, and certifications (Cristiano and Guagni, 2022). Also, the experiment conducted about the amount of carbon emissions for the snail-derivate cosmetic process concluded that the process is more effective on carbon emissions and soil protection criteria, which makes slime a sustainable alternative biomaterial in cosmetics considering production processes (Novara et al., 2022).

3.1.2.5.4. Companies Producing and Using Snail Slime

The use of snail slime in cosmetics is increasing rapidly, so brands are adding it to their products. There are several specialized smaller companies, labs, and startups that have the purpose of providing bio-based products, and there are even some brands completely focusing on snail-based materials, along with bigger and luxurious brands that are adding slime as an ingredient. MyAnisha is a Chilean-Italian natural cosmetics brand that is specialized in snail-based cosmetics. The brand started as a snail provider for gastronomic purposes but then switched to a snail-based cosmetic material and product producer. The company provides 100% pure snail slime-based masks and creams to their customers who are wellness and business centers, stores, and other private customers. They produce the material and products themselves on their farms where they breed snails (MyAnisha ®, 2023). Nuvò Cosmetic is another Italian brand that specializes in snail-slime-based cosmetics that breeds their snails on Garda Lake. The brand provides pure snail slime and cosmetics and care products that contain that slime. The products they provide are listed as face creams and serums, body scrubs, eye serums and contours, hair masks, and body and anti-cellulite creams (Nuvò Cosmetic, 2023). Royer Cosmetique is a French brand who is specializes in natural and organic snail slime-based cosmetics and personal care products. The company sells both hair and face care products ranging from snail-based soap, shampoo, eye contour, face serum, anti-aging, and anti-acne products (© Royer Cosmétique, 2023). Lumea is another Italian snail slime-based cosmetic brand that is under the bigger brand of Erboristeria Como, a natural cosmetics brand. Under the brand name Lumea, the company markets snail slime including serums, masks, moisturizers, and micellar water (Erboristeria Como ©, 2022). Nume-Lab is a Swiss natural cosmetics and

personal care brand that formulizes its natural products with sustainable purposes. Snail slime is one of the precious materials that are present in their products, ranging from exfoliating cleansers, peelings, face and eye serums, and creams (Nume Lab Switzerland ©, 2023). Wonder Company is another Italian brand that sells bio-based cosmetics that contain several materials derived from different plants and animals. The brand has a collection of snail slime which contains face and body serums and creams (Wonder Company Milano ©, 2018).

3.1.3. Other Biologic Organisms as Biomaterials in Cosmetic Products

3.1.3.1. Algae

3.1.3.1.1. Algae Material in Cosmetics Field

Seas and oceans are very vast sources that occupy more than three-quarters of the world, creating homes for many different living organisms and species. Abundant resources from seas and oceans have always been an interest for people and industries that are seeking more renewable, biological, and less harmful materials and production, waste, or recycling processes. Recently, rather than being a simple source of material in production processes, these materials from water lands are becoming more and more important for implementing and improving sustainability and environmentally-conscious actions (Wang et al., 2014) One of these most known and precious organisms living in aquatic environments is algae. Algae are a wide and diverse group of biological organisms, living in aquatic areas such as oceans, seas, lakes, and other humid natural environmental areas, in addition to some soils or lands that have humid environments, and icy and snowy surfaces (Orejuela-Escobar et al., 2021). Algae is differentiated from plants since they don't have plant-specific organs such as roots, leaves, and stems. Also, their energy production and reproductive systems varied compared to plants (Andersen and Lewin, 2023).

The green algae is the most known kind of algae to society, because of their larger relative size and more commonality of the seaweed form in oceans and seas. Green algae owe their color to the pigment called chlorophyll (Chapman, 2013). Chlorophyll is one of the many green color pigments which can be found in many plants and other microorganisms. Many types of macroalgae and microalgae may have photosynthetic functions, meaning that they can produce their energy and oxygen to survive and use them for their basic functions (Simon and Helliwell, 1998). Thanks to the existence of chlorophyll and light-absorbing mechanisms in their systems, their photosynthetic functions help algae to become a precious source of a biological and sustainable material that can be used in many sections of life, when they exist in their optimal

living conditions such as humid environment, having natural light and pH levels (Orejuela-Escobar et al., 2021). Due to them being these different and many, algae poses an amazing opportunity for many traditional and industrial uses for human life (Khan, Shin, and Kim, 2018). To sum up, algae is a miraculous sustainable, and biological material that can be used in many aspects of human life and can make it easier and healthier. In many industries, algae are already frequently used such as agriculture, energy, nutrition, personal care, and cosmetics (Joshi, Kumari, and Upasani, 2018). Thanks to their natural capabilities and their formation, it is certain that algae is a precious source that should be applied to especially cosmetics and personal care industry, which has many controversies going on about sustainability and health issues, due to the artificial and poisonous compounds used in products, packaging and disposal.

In many past research, it has been found that algae have many different beneficial compounds that make it very appropriate to be used in cosmeceutical fields. According to this past research, the most known cosmeceutical properties of algae are antioxidant, antimicrobial, anti-inflammatory, anti-aging, anti-cancer, and anti-melanogenic (Thiyagarasaiyar et al., 2020). In addition to these, it has become clear in this research that algae extracts are also significantly effective in protecting skin cells from UV radiation and damage, decreasing the risk of skin cancers, and supporting skin whitening in over-tanning conditions. Because of these proven facts, algae are commonly used in anti-aging or anti-wrinkle creams and sun protection lotions (El-Chaghaby and Rashad, 2021). Moreover, algae are found to be very effective as a moisturizer and hydration, making them very appropriate for the use of body lotions and hair care products. Algae owe their moisturizing benefits to their valuable polysaccharides inside, helping human skin to maintain its smooth texture and heal it in the presence of moisture loss. To sum up, thanks to their many beneficial compounds, algae are used in almost every product in cosmetics and personal care, from make-up products to shampoos, shower gels, and different types of creams (Singh and Purwar, 2022).

3.1.3.1.2. Production and Processing Methods of Algae

There are several different processing methods of algae depending on the areas that algae extract to be used. There are generalized extracting methods of algae that enable extracts to be used in various areas including cosmetics and personal care products. These methods can be mechanical, chemical, or enzymatic depending on the target bio-compounds and area of use. Most common and preferred methods can be listed as microwave-assisted extraction, ultrasound-assisted extraction, fluid extractions, homogenization, and conventional solvent

extractions that may include chemical or organic solvents, following mechanical processing methods such as milling, beating, and pressing (Michalak and Chojnacka, 2014).

3.1.3.1.3. Pros and Cons of Algae in Cosmetics

Algae application to transform products into healthier and more sustainable forms has different advantages and disadvantages. First of all, algae can be obtained from water sources, which makes it a very abundant and applicable biological source to find. Additionally, the capability of algae to produce energy and nutrition makes it a very valuable source with many beneficial nutrients to be used in cosmetics. Recently customers desire more bio-based and environmentally sustainable products so, algae is a source that would help these products be less harmful to people's health. While the algae substitutes some more hazardous chemicals in products, this transformation brings extra costs of production, since extracting and applying biological sources are relatively more costly to widely used chemical substances. On the other hand, previous studies make it clear that algae use in products is sustainable in many ways, but the LCA of algae usage in cosmetics is still limited. For now, it is not concluded yet if algae usage in cosmetics has a significant effect on reducing carbon footprints, especially at the disposal step. The most detailed LCA of algae use is done in the food industry, more research should be conducted to assess the sustainability of algae usage (Nakhate and Van der Meer, 2021). Finally, research on the possible negative effects of algae usage in cosmetic products is limited. In many research, the potential benefits of algae on the skin are mentioned, but in contrast, more research on possible problems, allergies, and side effects due to algae in products may be questioned more (Thiyagarasaiyar et al., 2020).

3.1.3.1.4. Companies Producing and Using Algae

In recent years, algae has been a widely used biomaterial by many cosmetics companies, from sustainable startups to well-known big companies. Examples of big companies that are using algae in their products can be given as Dove and L'Oréal Paris. While Dove was using algae as a moisturizer in their shampoos, L'Oréal includes algae in their face masks to benefit its cleansing and anti-acne properties. Also, the high-end Swiss cosmetics brand La Prairie uses snow algae inside its anti-aging creams. In addition to these famous brands, algae is used in many other smaller and local brands such as Nykaa, an Indian brand that produces body serums, Algenist, which uses algae in eye serums to reduce dark circles, Osea, produces algae-based lip and eye creams, Jenelt, in their sunscreens and Aubrey Organics, that uses algal proteins in their hair masks to protect hair tissue and strengthen it (Joshi, Kumari and Upasani, 2018). The

company Algatech is processing algae and it owns many sub-brands that use algae in many sectors including cosmetics, fuel, and fertilizers. The company works on microalgae and supports different industries and brands that desire to use microalgae as a sustainable biomaterial.

3.1.3.2. Fungi

3.1.3.2.1. Fungi Material in Cosmetics Field

Fungi have been a great natural source for humans in many different ways, especially as a food source. On the other hand, fungi are also valuable bio-sources that can be used as a raw material in many other different industries. Increasing the importance of environmental concerns made fungi even more important as a sustainable biomaterial. Mycelium, also named mycelia, is a vegetative form of fungi that is commonly used as a bio-based material in agriculture, construction, textile, cosmetics, design, and others. Mycelium is considered an important biological source and material because of its capability to decompose agricultural or biological wastes and transform them into organic materials and compounds that can be used by other living organisms such as plants and trees (Abhijith et al., 2018). Mycelium is defined as the network of long threads of fungi, mostly found under the soil. Mycelium is crucial for the well-being of the soil and the ecosystem and is a potentially sustainable and biodegradable material. Mycelium is mainly composed of distinct organic polymers such as proteins, chitin, cellulose, and fiber, which makes mycelium a valuable and appropriate source to be used in various industries' products (Haneef et al., 2016).

Even though fungi or mushrooms are mainly considered food resources, with an increasing trend of health concerns and awareness of green materials and processes, fungi become an important source that can be used in many various products such as cosmetics and personal care products. Specific types of fungi and mycelium have significant beneficial properties that can help human skin in many different ways. Moreover, being a biological and organic material, mycelium-based products become remarkably healthier options for both human health and the environment, decreasing the use of chemical substances and toxic, non-degradable wastes (Manan et al., 2020).

To begin with, it is found in past research that mycelium obtained from specific types of fungi has protective effects on UV lights and radiation, eventually helping to defend the skin against aging and wrinkling. These sun protection effects of mycelium make it a very suitable biomaterial for sun-protection creams and body care lotions. Additionally, mycelium extracts

are also effective for protecting the skin against irritation, allergies, and freckles which can show up frequently with the use of chemical compound-based sunscreens and other body lotions, which can also function as skin-whitening products (Cheng et al., 2018). Many other studies supported that mycelial extracts have positive effects on wrinkling and skin aging, but also found out that mycelium extracts have moisturizing properties that can help the skin to maintain its hydration and can support the hydration and softening of the skin in the conditions in which the skin has lost its elasticity and become flawed (Jo et al., 2021).

According to past research, many edible mushrooms and their mycelia have antioxidant, anticancer, antimicrobial, anti-inflammatory, and regenerative properties. Thus, the anticancer, anti-inflammatory, and regenerative properties of fungi mycelia become appropriate for substituting with synthetic chemicals in personal care products. In short, fungi mycelium is convenient mostly for external applications on the skin such as creams, lotions, and body and face washes and these applications are attractive to customers who desire less chemical-based products (Morris et al., 2017). In recent research that conducted the trials of Asian fungi in cosmetics, it has been found that extracts of this specific fungi are suitable for skin masks and sleep masks thanks to their rich and substantial benefits to skin health. The acidic compounds and nourishing polysaccharides of the mycelium and fruiting body of the fungi helped it to become a valuable biomaterial that can be used in skincare products, especially on the products that are applied topically (Kanlayavattanaku and Lourith, 2023).

3.1.3.2.2. Production and Processing Methods of Fungi and Mycelium

Mycelium cultivation is considered a convenient process when the fungi are provided with optimum nutrition and environmental conditions. Mycelium extracts that are used in products are most commonly obtained by fermentation methods. When optimal conditions are provided, fungi growth takes 5 to 14 days, and then the fermentation process starts to obtain active bio-compounds and polysaccharides to obtain the mentioned benefits from mycelium. In case of the large volume of production needed, fermentation is the best method to be applied (Vandelook et al., 2021). Another method to obtain mycelium extracts is to create powder by drying the fungi with heat and transforming it to become a powder. In past clinical experiments, this dry powder of fungi is dissolved by water and specific chemicals such as ethanol to capture beneficial substances such as antioxidants. The important point while collecting the extract is not to lose the bioactivity of the compounds and to exhibit the antimicrobial and antioxidant effects of the mycelium (Taofik et al., 2016).

3.1.3.2.3. Pros and Cons of Using Fungi in Cosmetics

In terms of many aspects, mycelium is a miraculous product, being antioxidant, anti-inflammatory, antimicrobial, regenerative, and healing at the same time. Fungi are a type of organism that can exist and grow easily, so fungi are an abundant and available biological source. Fungi mycelia and the waste of fungi are almost completely bio-degradable and compostable, which makes it a strong sustainable material that can conveniently be transformable for use inside or outside of the products. Moreover, fungi have been widely used for past decades as a medicinal substance, which means it has built trust as a safe product in customers' minds. In various past research, it has been found that the mycelium process and fabrication are low-cost, making it a sustainable biomaterial from an economic view (Manan et al, 2021). Some of the medicinal research done on fungi extracts mentioned that some types of mycelium may cause mild reactions or allergies depending on one's specific health conditions (Dennett, 2021). Various research also mentions the need for further research on whether there are possible risks regarding the toxicity of the specific fungi types. Nevertheless, fungi mycelium seems to be a feasible, safe, and sustainable biomaterial that can be easily applied to personal care and cosmetic products (Vandelook et al., 2021).

3.1.3.2.4. Companies Producing and Using Fungi

Shroom Skincare is a distinctive American company in the personal care industry that provides fungi mycelium-based vitamin serums for the face and body. The serum they promote helps to renew the skin cells and fight against skin aging, owing to mycelia's anti-inflammatory and antioxidant properties. The company is also against animal testing, using paraben and preservatives, in addition to the products being vegan. One of the primary aims is also to use bio-based materials, reduce waste, support environmental sustainability, and decrease CO2 emissions (Ferrer, 2023). Symrise is a German company that produces and sells natural and sustainable products both in the food and cosmetic sectors. In the cosmetic section, the company provides fragrances, skin, and health care products. Symrise has released a product named Symhair Thermo, which has mushroom mycelia inside the products and helps hair to be protected from heat. (Patel, 2022). Sawubona Mycelium is a South African biotechnology start-up that produces and sells mycelium extract to cosmetic companies. It aims to increase the use of natural and bio-based products to be used in cosmetics, pharmaceutics, food, and other industries. The company also produced hydrating and anti-aging skin serums containing mycelium under the brand Blu Beryl (Engineering News, 2022).

4. DEVELOPMENT STATUS OF BIOMATERIALS

The development status of a material can be defined as the level of development in each technology, method, or sector where that specific material can be used in the most effective way possible. With the development status of a material, it can be understood in which industry a material can be used more effectively and which properties of that material provide this effectiveness in specific industries. Moreover, it can be understood which materials are more effective in a particular area when compared with other materials. The development status of bio-based materials is very crucial since sustainable material use is one of the most valid trends in many industries, and appropriate application and processing of these materials is a must to obtain both environmentally and economically sustainable, socially accepted, and effective products.

In this section, each biomaterial will be examined by various criteria to understand how developed it is, mainly focusing on its use in the cosmetics and personal care industry. The development status of each material will be evaluated in detail and summarized in tables, including information such as its category, processing methods in the cosmetics field, the forms it is utilized in cosmetic products, examples of the companies that provide these materials in the mentioned forms and application areas which means the sectors the material is appropriate to be used. In addition to these, these tables contain other evaluation criteria that are grouped by characteristics of origin, end-of-life behavior in LCA, environmental impact in terms of water and carbon footprint, and aesthetic characteristics.

Aesthetic characteristics, including physical and mechanical properties, are some of the main decision criteria to understand if a material can be used in specific industry products such as energy, construction, packaging, textile, medicine, cosmetics, and more. As for biomaterials, one of the most important properties to understand its development status is its environmental impact and other sustainability criteria, along with aesthetic and mechanical properties and origin. Moreover, origin and sustainability criteria are also very important in the context of cosmetics and personal care since there is a serious concern for human and animal health.

Sustainability criteria consist of properties that are related to the life cycle assessment (LCA) of the material, especially the end of the life cycle, which can be listed as biodegradability, renewability, recyclability, composability, landfill, biocompatibility, carbon footprint (Greenhouse Gas Emissions or GHG) and water footprint. All these LCA-related criteria are explained in detail in the next section. Aesthetic characteristics determine in which ways and

forms a product/material can be transformed, therefore implying to which type of products or industries that specific material can be applied. These characteristics can be exemplified as texture, transparency, and malleability.

4.1. Life Cycle Assessment (LCA) of Biomaterials & Criteria

Life Cycle Assessment is a tool that is used to define and evaluate the environmental impact associated with a product's life, from beginning to end, including the use of raw materials and sources, production processes, and the way it is discarded. LCA is a broad tool that can be applied to a wide range of goods and services, evaluating a product's impact from various perspectives including environment, waste management, human health, and economy (Finnveden et al., 2009). Since it is a tool that considers different perspectives and criteria, LCA has become one of the most appropriate tools to evaluate different types of biomaterials used in cosmetics and has been chosen as a comparative tool to assess the environmental footprint of each material.

The following criteria have been defined to understand how each biomaterial can be classified and evaluated in terms of environmental impact. While the first six criteria have been evaluated in a general way since all biomaterials have these properties at a certain level, numerical data has been used to evaluate and compare all materials with each other in terms of carbon and footprint, which can be seen in the development status section of each material.

4.1.1. End of Life Cycle & Recyclability

End-of-life (EOL) is defined as the last cycle of a product's life and it is concerned with the processes a product is going through after its use is finished and is about to be discarded. The decisions related to the end-of-life cycle of a product are about how the disposal of the product will be handled and in which way the waste is controlled. Recycling procedures, incineration, regulations of waste, and whether the product will be upcycled or downcycled are important decisions to be made in terms of environmental and economic sustainability (© Eco Cost Value, 2023). Recyclability is an important assessment tool to define in what context a material can be recycled after its main use and what will the value of the new material be compared to the original material (Villalba, 2002). Depending on the value change in the transformation process, recycling can be divided into two groups which are named upcycling and downcycling. The ratio of the recyclability of a product is very important in terms of controlling the amount of bio-waste regarding the biomaterials. Waste of fruits, other plants, and animal-derived materials should be assessed in terms of their recyclability and the change in the value of the original

material. These assessments are crucial for understanding which material is more suitable for application in each cosmetic product and the impact of these processes.

4.1.1.1. Upcycling

Upcycling is the process of transforming wasted, unwanted, and inefficient products and materials into new reusable materials and products, in which in the end newly obtained material is superior to the primary product in terms of quality. Upcycling is a value-added process that supports both environmental and economic sustainability by increasing the value of unused materials by converting them into more economical, high-quality, environmentally-friendly, and durable forms (Wegener, 2016). The presence of upcycled materials has been increasing recently and the most used areas of upcycled materials are accessories, textiles, art, and food supplements, but more areas of use are developing each day for upcycled materials (‘’Upcycling’’, 2023). Recently, upcycled plants or unused animal-based products have been increasingly used as upcycled materials in cosmetics and personal care products.

4.1.1.2. Downcycling

Down cycling is the process where waste and unused materials are transformed into lower-quality of materials to be used again. Down cycling changes the primary structure of the product and the new form of the product may become weaker less efficient, and less valuable (Helbig et al., 2022). However, downcycled materials are still appropriate for use and create a good opportunity for eliminating risky waste, greenhouse gas emissions, water, and air pollution. The most common materials that are downcycled are plastic, paper, and metals which are transformed into the materials that are used in automotive and construction sectors, in which the strength and quality loss in materials is negligible (‘’Downcycling’’, 2023).

4.1.2. Landfill Gas

Landfill gas is the mixture of natural gases produced in the process of the decomposition of organic wastes such as food waste, paper waste, and animal waste in a landfill. Landfill gas is composed of methane and CO2, with almost the same proportions. Methane and CO2 are two important hazardous gases that constitute greenhouse gas emissions (GHG), therefore LFG emissions are crucial in the context of environmental sustainability and climate change and, should be controlled (USA Environmental Protection Agency, 2023). In addition to environmental damage, LFG emissions may also cause health and security issues in the landfill due to contamination. Governmental regulations to control LFG include decreasing the bio-waste by recycling and utilizing LFG by production plants as a renewable source, of heat,

electricity, or fuel (''Landfill Gas'', 2023). In the context of this paper, biomaterials in cosmetic products consist of fruits, plants, microorganisms, animal derivatives, and their wastes, which are completely biological and have decomposition properties of mentioned bio-wastes. LFG emission level is an important KPI to measure and evaluate the impact of each biomaterial used in cosmetics instead of chemical substitutes and decide which will be more effective and environmentally sustainable in terms of contributing GHGs.

4.1.3. Biodegradability

Biodegradation is defined as the natural process of breakdown of an organic material, mostly by microorganisms such as bacteria and fungi. Biodegradability can be defined as the ability and ratio of a substance to degrade in nature. Biodegradability is an important indicator in the context of environmental sustainability since degradation causes the release of greenhouse gases such as CO2. The level of biodegradability of a material is crucial to define if that material is suitable to be used in specific products (Garrison, Murawski, and Quirino, 2016). Bio-based materials like fruit, vegetable, and animal wastes are types of materials that degrade faster in nature compared to commercial materials such as plastic, paper, or glass (Science Learning Hub, 2008). That's the reason why the biodegradability of a material is important to consider when deciding which material should be used as cosmetic ingredients and how it should be processed or transformed.

4.1.4. Biocompatibility

Biocompatibility can be defined as the ability of a material to adapt and perform in the host it is in contact with. Biocompatibility can be considered as a material's effect or performance on the human body and how successfully it does its job without causing any harm to health. In terms of skincare, biocompatibility can be explained as the appropriate formulation and use of non-toxic materials, that do not cause irritations, allergies, or other problems, show the expected benefits, and create harmony with the body's natural processes. Materials that are more bio-based and less chemical are known to be more biocompatible with skin, that's one of the reasons why bio-based cosmetics are becoming more important in the eyes of consumers (Coltelli et al., 2020). Biocompatibility of biomaterials in cosmetics is significant to understanding which material is suitable for cosmetic products to be non-allergic and non-toxic, especially for special skin conditions. Thus, the biocompatibility of each biomaterial should be defined and compared with each other to discover better material options and formulations of products.

4.1.5. Renewability

The origin of a material determines its life cycle and impact on the environment. Fossil-based materials are finite sources that cannot be replenished for a long period, while renewable sources can be replenished in a short period and can be used continuously. Renewable materials are mostly derived from biological sources such as animals and plants, and serve the needs of society more sustainably (Rajput, Samoylov and Hai, 2023). Thus, renewable sources are becoming more important in almost all industries recently. Even though bio-based materials are considered renewable sources and a good way to support environmental and economic sustainability, bio-based sources still have impacts on the environment. The renewability of a material depends on several conditions such as the type of bio-waste, production technologies, country conditions and regulations, and the entire life cycle of the biomaterial (Contreras, 2015). The origin of the biomaterial and its renewability is important to identify the use of biomaterial in cosmetic products and technologies to be chosen.

4.1.6. Compostability

Compostability can be defined as the ability of a biological product to be decomposed naturally into organic materials and enrich the living organisms in the soil, acting as fertilizer or other valuable organic compounds. Composing happens when there are suitable conditions such as temperature, humidity, and availability of decomposing organisms such as bacteria, worms, and fungi (Chen et al., 2011). The compostability of a product is important in the context of environmental sustainability and is directly relevant to waste management and greenhouse gas emissions. Increasing the amount of bio-based materials in a product increases its level of compostability in the soil, therefore reducing its environmental impact. Several studies have shown that increasing food waste is a threat to the environment and decomposing these wastes is far better than landfilling or incineration in terms of carbon and water footprint (Saer et al., 2013). All this information supports the idea that products with more bio-based materials are more compostable and naturally recyclable. Hence, the compostability of biomaterials is an important criterion to define how they decompose in their end-of-life process and on which level they impact the environment.

4.1.7. CO2 Footprint

Carbon footprint is an impact indicator for defining the amount of CO2 and greenhouse gas emissions created by a specific product, activity, or process. Decreasing carbon footprint is one of the main purposes of many organizations recently, to respect the future and environment

from many perspectives. Replacing synthetic, inorganic, chemical, and non-recyclable materials with bio-based and renewable ones is one of the most effective methods to decrease the carbon footprint of a product (© Cosmetics Europe-The Personal Care Association, 2018). Therefore, many brands are changing their processes and materials to be more sustainable. The CO2 Footprint indicator is an appropriate tool to compare biomaterial options and decide which ones are less impactful regarding GHG emissions in the context of cosmetic use. Biomaterials used in the product, processing of these materials, disposal of the products, and all other steps in bio-based cosmetic production have contributed to carbon footprint, hence, all life cycle of materials and all the processes needed should be examined to define the CO2 footprint (Francke and Castro, 2013).

4.1.8. Water Footprint

Water footprint or water use can be defined as the water consumption of a specific product, process, company, or nation. Water is a finite source and water consumption is a crucial matter in terms of sustainability and the future of the next generations. Fruits and vegetables, or plants in general, as relevant biomaterials in cosmetics, have a significant effect on water footprint due to the large amount of water use in their production processes. Water consumption may depend on the technology used, the type of production, and type of the plant (Trajer, Winiczenko, and Drózdz, 2021). Calculating the accurate water footprint for each possible material is crucial to transforming product formulations and processes according to green and sustainable production purposes. Water is a source that is used in every stage of cosmetic products' life cycle and constitutes a high percentage of products' ingredients. Since the cosmetic industry consume water in significant amount of and their water footprint is high, new sustainable methods and materials to decrease water use is vital for the industry (Aguiar et al., 2022). The water footprint of biomaterials used in cosmetics is a helpful indicator to define which biomaterial is less impactful to the environment in terms of water use.

4.2. Development Status of Biomaterials

4.2.1. Development Status of Algae

Algae is a biological organism that exists and lives autonomously in aquatic environments, and it is being used as a bio-based material in different areas of human life and professional industries. Due to its rich nature of bio-active compounds, conveniently processable physical structure, high availability, and a biodegradable, compostable, renewable, recyclable, and biocompatible natural source, algae use is very widespread around different industries such as

textile, agriculture, packaging, energy, culinary, pharmaceuticals and cosmetics (© JavaTpoint, 2023). Therefore algae can be mentioned as a biomaterial that has the widest area of application compared to other biomaterials mentioned in this work.

In the beauty field, algae use is not as common as other plant-based materials. Algae material is added into product formulations in the form of algae extract, oil, or powder. These cosmetic biomaterials can be obtained with heat treatment, enzyme, microwave, ultrasound-assisted extraction methods or with organic, water, and chemical solvents, depending on the product type and target bio-active compounds (Michalak, Tuhy and Chojnacka, 2015). Most known cosmetic material suppliers companies such as Carrubba, BotanicalsPlus, LEV, Algatech, MakingCosmetics, Croda, Biogründl, and BASF provide algae-based materials which formalized for cosmetic uses (© SpecialChem, 2023).

There is no available information present in the literature regarding the carbon and water footprint of algae production. There is also a lack of studies about algae-based cosmetic products' carbon and water footprint assessments. That may be due to algae being a biological organism that does not require human intervention in its existence and growth. There are only a few studies in the literature about the footprint analysis of algae-based biofuels. Further research may be conducted about the sustainability of cosmetic products that contain algae, especially in cases where algae are substituting chemical materials.

Material: Algae			
Category:	Biologic Organisms	**Forms used (cosmetics):**	Algae extract, oil, powder
Manufacturing Processes:	Heat treatment, enzyme, microwave, ultrasound-assisted extraction, chemical solvents	**Producer Company Names:**	Carrubba, BotanicalsPlus, LEV, Algatech, MakingCosmetics, Croda, Biogründl, BASF
Application Areas:	Cosmetics, textile, agriculture, packaging, energy		
Origin:		**End of Life:**	
Renewability	Yes	**Type of Recycling**	Upcycling
Recyclability	Yes	**Compostability**	Yes
By-product Availability	No	**Bioodegradability**	Yes
Source of Product	Bio-based	**Landfill**	Yes
Aesthetic Characteristics:		**Environmental Impact:**	
Texture	Smooth	**Carbon (co2) Footprint (kg/kg prd.)**	N/A
Transparency	High	**Highest impact stage:**	N/A
Malleability	Elastic	**Water Footprint (lt/kg)**	N/A

Table 1: Summary Table of Algae Material Properties

4.2.2. Development Status of Aloe Vera

Aloe vera is a plant-based biomaterial that is widely present in people's lives and the products they use. Being mostly used as a decorative plant inside houses, its natural elements and various bio-active compounds make aloe vera a preferred material in culinary, medicine, cosmetics,

and personal care. In addition to beauty products, the physical characteristics of the plant, like its texture and elastic fibers, also make aloe vera appropriate as a sustainable material option in textile and packaging industries, as a substitute for plastics or synthetic fibers (Mondal, Saha, and Rahman, 2021). Being easily biodegradable and compostable also advantages of aloe vera as a good substitute material for these industry products.

In cosmetics and personal care products, aloe vera is used in aloe vera extract, juice, gel, and powder form, depending on the type of product or target skin type. Upcycling wasted aloe vera leaves, wood, and flowers is one of the good ways to obtain these biomaterials for different uses (Martínez-Sánchez, 2020). Some of the most common practices applied to aloe vera to formulate cosmetic materials are grinding, pressing, filtration, heat treatments, pasteurization, and enzymatic extraction methods. Biomaterial supplier firms such as Biogründl, Naturalin, Specialty Natural Product, Natuva, ICSC, The Herbarie, Biocosmethic, Aloe Corporation, Mexialoe Laboratorios, and many others provide aloe vera extracts, juices, gels or powders for cosmetics and personal care companies who need these materials (© SpecialChem, 2023).

Like other naturally grown plants and biological organisms, there is no information present in the literature regarding the carbon or water footprint of the aloe vera plant. Further research may focus on aloe vera containing sustainable cosmetic products and their carbon and water footprint to assess how this material affects their sustainability in general. However, aloe vera has been used as a plant and traditional beauty ingredient for years, and since there is no negative information regarding its safety or any environmental harm reported, it is considered a safe and sustainable material that is often included in cosmetic formulations.

Material: Aloe Vera			
Category:	Plant-based	**Forms used (cosmetics):**	Aloe vera extract, juice, powder, gel
Manufacturing Processes:	Grinding, pressing, filtration, heat treatments, pasteurization, enzymatic extraction	**Producer Company Names:**	Biogründl, Naturalin, Specialty Natural Product, Natuva, ICSC, The Herbarie, Biocosmethic, Aloe Corporation, Mexialoe Laboratorios
Application Areas:	Cosmetics, medicine, culinary, textile, packaging		
Origin:		**End of Life:**	
Renewability	Yes	**Type of Recycling**	Upcycling
Recyclability	Yes	**Compostability**	Yes
By-product Availability	Yes (leaves, flowers)	**Bioodegradability**	Yes
Source of Product	Bio-based	**Landfill**	Yes
Aesthetic Characteristics:		**Environmental Impact:**	
Texture	Smooth, slimy (gel)	**Carbon (co2) Footprint (kg/kg prd.)**	N/A
Transparency	High	**Highest impact stage:**	N/A
Malleability	Elastic	**Water Footprint (lt/kg)**	N/A

Table 2: Summary Table of Aloe Vera Material Properties

4.2.3. Development Status of Banana

Banana is a fruit-based biomaterial that is increasingly used in many different industry products. Banana is rich in antioxidant, vitamins, and minerals, which makes it a great source as a biologic cosmetic ingredient, helping several skin conditions. Being a biological material and having been used for years as a traditional beauty ingredient, banana is proven to be biocompatible to the human body. Moreover, the banana is a very widely harvested plant, which is highly biodegradable, and its byproducts such as peels, seed, and stem that are considered waste are very appropriate for recycling, especially for upcycling.

Bananas can be used in cosmetic formulations in the forms of fruit extract, peel, and peel powder where the needed bio-active compounds can be obtained. Like fruit, banana wastes such as peels, seeds, and other parts of the plant are available for the extraction of valuable ingredients. Grinding, milling, chemical and mechanical extractions and organic and chemical solvents are the most commonly used extraction methods to obtain materials for cosmetic formulations. There are several suppliers of banana-based extracts to cosmetic brands who desire to add banana-based materials to their products, and some of these suppliers can be listed as Solabia, Akott, Bioveda Naturals, Aqia, BotanicalsPlus, Natuva, Biogründl, Carrubba and Peter Jarvis (© SpecialChem, 2023).

Other than cosmetic formulations, banana is used in other industries such as textile, accessories, and decor objects, with materials produced mostly from the peels of the fruit. Due to banana peels having a soft and elastic texture, and being full of fibers, fabric from bananas is obtained easily and becomes a sustainable and healthy material for textile products (Bananatex ®, 2023). Individual designer works also include the transformation and use of banana waste as a material in daily accessories or objects (Material Driven, n.d.). Additionally, banana peels have also been experimented with several times in the past and found to be appropriate for producing bioplastics and to be used as a biodegradable and compostable packaging material (Pongsuwan et al., 2022; Ramadhan and Handayani, 2020).

In the context of CO2 and water footprint, banana production can be considered environmentally sustainable when compared to other plant and animal-based biomaterials that are used in cosmetics. Banana has a carbon footprint of 0, 46 kilograms of CO2 released for one kg of fruit production, with the most impactful stage being end-of-life, due to the high amount of waste and low composting rate of banana (Mersereau, n.d.). On the other hand, the average water footprint of a banana is around 790 liters per one kg of banana production, which

is moderate compared to other fruits, and less compared to other biomaterials that are derived from other plants or animals (https://evgenii.com/water-footprint/en/). In summary, banana is a plant-based biomaterial that has a low impact on the environment and is a sustainable source that can be replaced with synthetic materials in cosmetic and personal care products.

Material: Banana			
Category:	Fruit/Plant-based	**Forms used (cosmetics):**	Fruit extract, peel, peel powder
Manufacturing Processes:	Grinding, milling, chemical and mechanical extractions, organic and chemical solvents	**Producer Company Names:**	Solabia, Akott, Bioveda Naturals, Aqia, BotanicalsPlus, Natuva, Biogründl, Carrubba, Peter Jarvis
Application Areas:	Cosmetics, textile, objects, packaging		
Origin:		**End of Life:**	
Renewability	Yes	**Type of Recycling**	Upcycling
Recyclability	Yes	**Compostability**	Yes
By-product Availability	Yes (Leaves, peel, inflorescence, stems)	**Bioodegradability**	Yes
Source of Product	Bio-based	**Landfill**	Yes
Aesthetic Characteristics:		**Environmental Impact:**	
Texture	Soft	**Carbon (co2) Footprint (kg/kg prd.)**	0,46
Transparency	Medium	**Highest impact stage:**	End-of-life
Malleability	Elastic	**Water Footprint (lt/kg)**	790

Table 3: Summary Table of Banana Material Properties

4.2.4. Development Status of Blueberry

Blueberries are valuable plant-based materials with high antioxidant capacities and many health benefits. Being a biological source, blueberry is a highly biodegradable, compostable, and renewable material which makes it a sustainable choice for both environmental and economic purposes. Many sustainable startups and known brands upcycle blueberry fruits which are wasted, and use them as raw materials substituting health-threatening chemicals in cosmetics and personal care industries. Additionally, blueberry fibers are also useable as a dye material for textile products and objects (Phan et al., 2020). The smooth, elastic, and gummy texture of the blueberry fruit may realize its potential use in other industries such as textile or packaging, however, there are lack of evidence and experiments in the literature on this field that proves blueberry use in these industries is logical.

In cosmetic formulations, blueberries are used in the forms of fruit extract, juice, and powder, which can be extracted from the fruit itself, leaves, and stem of the blueberry plant. To obtain valuable compounds for the skin, the most commonly used methods are mechanical and organic solvent extraction, ultra-sound, and electric-assisted extraction (Loncaric et al., 2020). BioOrganic Concepts, Carrubba, Morechem, BotanicalsPlus, Green Source Organics, and OQEMA are some of the blueberry extract producers and suppliers that provide blueberry materials for cosmetic formulations (© SpecialChem, 2023).

Blueberry production has a moderate impact on the environment. The average CO2 footprint of blueberry production is 0, 99 kg of CO2 per one kilogram of fruit produced. The most impactful stage that most gases release is the harvesting phase, where many chemicals, machines, and technology are used (Mersereau, 2023). On the other hand, the average water footprint is 845 liters of water for one kilogram of fruit (https://evgenii.com/water-footprint/en/). Compared to other biomaterials, the impact of blueberries in terms of CO2 and footprint is moderate. As for other fruits, blueberries are more impactful compared to citrus, banana, and pineapple, while they are less impactful compared to coffee, coconut, olive, tea, and other animal-based biomaterials.

Material: Blueberry			
Category:	Fruit/Plant-based	**Forms used (cosmetics):**	Fruit extract, powder, juice
Manufacturing Processes:	Mechanical & organic solvent extraction, ultra-sound & electric-assisted extraction	**Producer Company Names:**	BioOrganic Concepts, Carrubba, Morechem, BotanicalsPlus, Green Source Organics, OQEMA
Application Areas:	Cosmetics, objects, dye		
Origin:		**End of Life:**	
Renewability	Yes	**Type of Recycling**	Upcycling
Recyclability	Yes	**Compostability**	Yes
By-product Availability	Yes (Leaves, stem)	**Bioodegradability**	Yes
Source of Product	Bio-based	**Landfill**	Yes
Aesthetic Characteristics:		**Environmental Impact:**	
Texture	Soft, gummy	**Carbon (co2) Footprint (kg/kg prd.)**	0,99
Transparency	Medium	**Highest impact stage:**	Harvesting
Malleability	Elastic	**Water Footprint (lt/kg)**	845

Table 4: Summary Table of Blueberry Material Properties

4.2.5. Development Status of Cacao

Cacao is a plant that has several health benefits to the skin, therefore, cacao is developed importantly for cosmetic use along with the use of culinary purposes. In the general context, the cacao plant is accepted as biodegradable, compostable, and recyclable, however, the levels of these properties differ with different parts and byproducts of cacao beans such as husk, hull, pulp, shell, and sweating. Less biodegradable parts such as beans are more appropriate for mechanical processing to produce powdered forms.

Cacao butter is the most widely known and used form of cacao in cosmetic products. In addition to cacao butter, cacao oil, powder, and extract are also suitable to be added to product formulations. Cocoa powder, oil, butter, and extracts can be obtained by the combination of complex mechanical and chemical processes including solvent and water extraction, grinding, toasting cleaning, micronizing, breaking, alkalization, roasting, and fermentation (Scapagnini et al., 2014; Sanchez et al., 2023). The rough and rigid nature of cacao beans makes this amount

of mechanical processing necessary to obtain extract, oil, and butter. Material forms suitable for cosmetic formulations are produced and supplied by several raw and processed material brands such as Teluca, Croda, Micro Powders, Akott, Biogründl, Vantage, Parnica, Symrise, and Durae Corporation (© SpecialChem, 2023).

Cacao is a very appropriate and healthy material for cosmetic formulations, but this is not the area it can be applied. Even though it is not completely developed and widely used yet, upcycled cacao wastes can be also applied to textiles, architecture, objects, and packaging. Kajkao is an Ecuadorian startup project where cacao wastes are transformed to obtain raw biomaterial to be applied in these industries as a sustainable material. The project is still in the experiment and development phase, along with pursuing partnerships with companies from relevant industries (© Lako Studio S.A.S., 2023; © DesignWanted S.r.l., 2023)

As for environmental impact, cacao and cacao-based products may show different numbers depending on the product forms. In the CO2 footprint context, raw cacao has 1, 47 kilograms of carbon emission for one kilogram of cacao production, with the most impactful stage of plantation due to deforestation of soil (Vervuurt et al., 2022). However, to produce cacao-based products such as cacao butter, the number can increase to 30, depending on the country of origin and product type (© CarbonCloud, 2022). On the other hand, while cocoa bean production requires the use of 20000 liters of water for one kilogram of bean production, this number increases to 35000 liters for one kilogram of cocoa butter production (https://evgenii.com/water-footprint/en/). These numbers show that cocoa-based cosmetic materials require a significant amount of water, especially compared to other materials, which may lead to several discussions over the use of cacao in cosmetics.

Material: Cacao			
Category:	Fruit/Plant-based	**Forms used (cosmetics):**	Extract, butter, oil, powder
Manufacturing Processes:	Grinding, pressing, solvent extraction, micronizing, breaking, alkalization, roasting and fermentation	**Producer Company Names:**	Teluca, Croda, Micro Powders, Akott, Biogründl, Vantage, Parnica, Symrise, Durae
Application Areas:	Cosmetics, pharmacuticals, culinary		
Origin:		**End of Life:**	
Renewability	Yes	**Type of Recycling**	Upcycling
Recyclability	Yes	**Compostability**	Yes
By-product Availability	Yes (husk, hull, pulp, shell, sweating)	**Bioodegradability**	Yes
Source of Product	Bio-based	**Landfill**	Yes
Aesthetic Characteristics:		**Environmental Impact:**	
Texture	Rough (bean), smooth (butter)	**Carbon (co2) Footprint (kg/kg prd.)**	1,47
Transparency	Matte	**Highest impact stage:**	Planting (deforestation)
Malleability	Rigid (bean)	**Water Footprint (lt/kg)**	20000 (bean)-35000 (butter)

Table 5: Summary Table of Cacao Material Properties

4.2.6. Development Status of Chitin

Chitin is a commonly used biomaterial that can be originated from animals such as bugs and fungi. Chitin is a biomaterial that has a specific rough and rigid texture since it is the fundamental compound of crustacean shells. These properties make chitin suitable for application in different industries such as agriculture, packaging, cosmetics, and personal care, mostly in a chitosan powder form (Triunfo et al., 2021). Being bio-based, chitosan is also biodegradable and compostable, especially when compared to synthetic materials it substitutes, thus it is considered as an environmentally sustainable material. Since chitin is obtained from living organisms, it is renewable by its source and appropriate for recycling since animal shells can be processed to be upcycled into chitosan powder and added to several products.

Chitin can be seen in cosmetics in the powder form of chitosan and chitoglycan, which can also be found in chitin byproducts like carotenoids, glucans, and other proteins. These cosmetic materials can be extracted by several processing methods including bacterial fermentation, enzymatic hydrolysis, and solvent extraction, to the animal shells or fungi (Casadidio et al., 2019). Primex, Chitinor, Clariant, Ovensa, Vink Chemicals, Qingdao Chibio Biotech, Dalian Handom Chemicals, and Kraeber & Co are some of the suppliers that present in the chitin-based raw material market (© SpecialChem, 2023).

In the context of environmental sustainability, it can be said that chitin has a significant impact on the environment in terms of CO2 and water emissions. For one kilogram of chitin production, approximately 59,2 kilograms of CO2 is emitted and more than 34000 liters of water is used (Riofrio, Alcivar, and Baykara, 2021). Chitin production portrays the highest level of environmental impact compared to other biomaterials in this research. These numbers show that, even though chitin is a healthy and valuable biomaterial option in cosmetics, in terms of water consumption and GHG emissions, it is not as sustainable as other options, therefore its use in cosmetics is debatable and not as common as other materials such as plants.

Material: Chitin			
Category:	Animal-based / Fungi-based	**Forms used (cosmetics):**	Chitosan, chitoglycan
Manufacturing Processes:	Bacterial fermentation, enzymatic hydrolysis, solvent extraction	**Producer Company Names:**	Primex, Chitinor, Clariant, Ovensa, Vink Chemicals, Qingdao Chibio Biotech, Dalian Handom Chemicals, Kraeber & Co
Application Areas:	Cosmetics, packaging, agriculture, culinary		
Origin:		**End of Life:**	
Renewability	Yes	**Type of Recycling**	Upcycling
Recyclability	Yes	**Compostability**	Yes
By-product Availability	Yes (proteins, carotenoids, glucans)	**Bioodegradability**	Yes
Source of Product	Bio-based	**Landfill**	Yes
Aesthetic Characteristics:		**Environmental Impact:**	
Texture	Rough	**Carbon (co2) Footprint (kg/kg prd.)**	59,2
Transparency	Matte	**Highest impact stage:**	Processing of chitin & chitosan
Malleability	Rigid	**Water Footprint (lt/kg)**	34450

Table 6: Summary Table of Chitin Material Properties

4.2.7. Development Status of Citrus Fruits

Citrus fruits are plant-based biomaterials with high levels of recycling capabilities. Large amounts of waste create great potential for upcycling the citrus byproducts to produce sustainable and healthy materials to be used in different areas. Like almost all bio-based products, citrus fruits are renewable, recyclable, compostable, and biodegradable materials that can be valorized in many ways to create more sustainable and healthy raw materials and business processes, along with decreasing the waste and carbon/water footprint of production facilities.

With the production and consumption of citrus fruits, different types of byproducts emerge such as peels, seeds, and leaves of the fruit or tree. These byproducts are rich in vitamins and antioxidants, therefore they turn into available bio-sources for cosmetic formulations, as mentioned before in previous sections. Citrus fruits are used in cosmetic products in various forms such as peel powder, oil, juice, and fruit extract. These material forms are obtained with several different processing methods including distillation, mechanical extraction, heat treatment, filtration, and other mechanical solvent, or chemical-assisted methods. Many cosmetic and raw material producers including Akott, Biogründl, Symrise, BotanicalsPlus, Durae, Clariant, and Cargill supply citrus materials to the companies who prefer to use those materials in their product formulations (© SpecialChem, 2023).

Citrus materials have soft and elastic textures, which make them suitable materials for textile applications (Orange Fiber S.r.l., 2023). Additionally, fibers obtained from citrus fruits are also used as a material in sustainable objects such as home decor (© Archiproducts.com, 2023). There is also some research stating that citrus fibers can be used as sustainable and

environmentally friendly packaging materials instead of plastics, thanks to their high level of biodegradability and compostability (Panwar et al., 2021).

As for environmental impact, the CO2 and water footprint of citrus fruits change depending on the type of citrus fruits, but in a general view, the average CO2 footprint of citrus fruits is 0, 66 kg for one kilogram of fruit production, which can be considered low compared to other plant and animal-based biomaterials. The most impactful stage of citrus fruits in their LCA is the end-of-life stage, which is the disposal stage in which landfill gases are released (Mersereau, 2023). The water footprint of citrus production also differs for fruit types, ranging between 400 to 700 liters per kilogram of fruit production, which is also considered moderate (Hoekstra et al., 2008).

Material: Citrus Fruits			
Category:	Fruit, Plant-based	**Forms used (cosmetics):**	Extract, peel, juice, powder, oil
Manufacturing Processes:	Distillation, mechanical extraction, heat treatment, filtration	**Producer Company Names:**	Akott, Biogründl, Symrise, BotanicalsPlus, Durae, Clariant, Cargill
Application Areas:	Cosmetics, textile, objects, packaging		
Origin:		**End of Life:**	
Renewability	Yes	**Type of Recycling**	Upcycling
Recyclability	Yes	**Compostability**	Yes
By-product Availability	Yes (Leaves, peel, seeds)	**Bioodegradability**	Yes
Source of Product	Bio-based	**Landfill**	Yes
Aesthetic Characteristics:		**Environmental Impact:**	
Texture	Soft	**Carbon (co2) Footprint (kg/kg prd.)**	0,66
Transparency	Medium	**Highest impact stage:**	End-of-life
Malleability	Elastic	**Water Footprint (lt/kg)**	400-700

Table 7: Summary Table of Citrus Material Properties

4.2.8. Development Status of Coconut

Coconut is a tropical fruit that is widely used as a plant-based biomaterial in cosmetics and personal care products. In addition to the various health benefits it provides to skin and hair, coconut is preferred also for its biodegradable, compostable, and renewable properties as a material. Coconut elements such as fruit, leaves, shells, and outer fibers are mostly wasted after the consumption of coconut water, therefore, these byproducts arise as naturally available raw materials, which can be conveniently upcycled for other uses in different industries.

In cosmetic formulations, coconut is used mostly in the form of virgin coconut oil, which can be extracted directly by mechanical methods from the fruit as has been mentioned in previous sections. In addition to oil, coconut is also added into cosmetic formulations with coconut extract, milk, and powder forms. The tough and rigid texture of coconut makes mechanical

processes such as pressing and pounding, necessary to obtain coconut oil, water, and extract, however, other methods such as heat treatments and solvent extractions are also used to capture some valuable bio-active compounds. Many different suppliers provide coconut extract, oil, and water for cosmetic use, some of them can be listed as Cargill, Siamplus, Solabia, Sophim, Carrubba, BioOrganic, Symrise, Aqia and Bioveda Naturals (© SpecialChem, 2023).

Cosmetics is not the only industry where coconut-based materials are used. Coconut fibers, which are also named coir, are obtained from the outer shells of the coconut and are being used at an increasing rate as a sustainable fabric in the textile industry (Martins and Sanches, 2019). Coir is a material that is used in home tools such as doormats, carpets, brushes, or mattresses. Moreover, it can also be used as a biodegradable and recyclable packaging material. In several sources, it is also mentioned that coconut fibers are also suitable for clothing production thanks to their appropriate texture and mechanical properties (Textile Value Chain, 2019; Mishra and Basu, 2020; McQuarrie, 2018).

Coconut fruit production has an average CO2 footprint level of 2, 1 kg of CO2 per kg of fruit production (Marie, 2023). This number is relatively high compared to other fruit-based materials such as citrus, banana, and blueberry. On the other hand, it still has less impact in terms of CO2 footprint than other plant-based materials such as coffee or tea. Additionally, the water footprint of coconut is around 2700 liters per one kg of coconut production, which is relatively high. When we examine coconut oil, the most commonly used cosmetic form of coconut, the water footprint increases to 4500 liters, which is significant (https://evgenii.com/water-footprint/en/). From this point of view, it is verified that the oil extraction phase is the most impactful stage of the life cycle, both in terms of CO2 emissions and water use.

Material: Coconut			
Category:	Fruit/Plant-based	**Forms used (cosmetics):**	Fruit extract, powder, milk, oil, pulp
Manufacturing Processes:	Heating, pressing, mechanical and solvent extraction	**Producer Company Names:**	Cargill, Siamplus, Solabia, Sophim, Carrubba, BioOrganic, Symrise, Aqia, Bioveda
Application Areas:	Cosmetics, objects, accessories, textile		
Origin:		**End of Life:**	
Renewability	Yes	**Type of Recycling**	Upcycling
Recyclability	Yes	**Compostability**	Yes
By-product Availability	Yes (Leaves, stem, shell, coir)	**Bioodegradability**	Yes
Source of Product	Bio-based	**Landfill**	Yes
Aesthetic Characteristics:		**Environmental Impact:**	
Texture	Rough	**Carbon (co2) Footprint (kg/kg prd.)**	2.1
Transparency	Medium - High	**Highest impact stage:**	Oil extraction
Malleability	Rigid	**Water Footprint (lt/kg)**	2700 (fruit), 4500 (oil)

Table 8: Summary Table of Coconut Material Properties

4.2.9. Development Status of Coffee

Another valuable plant-based biomaterial that is widely used in cosmetic formulations is coffee. Caffeine is one of the most important bio-compounds that is relevant for skin benefits, and caffeine can be obtained from the coffee beans and even waste or byproducts from coffee such as pulp, skin, bean, silverskin, parchment, and grounds, as it is explained in the previous section. These byproducts are very suitable and increasingly used for upcycling to transform redundant waste into valuable materials and different types of products. Coffee is an important raw source that can be substituted with harmful, synthetic, and unsustainable materials since it is more biodegradable, compostable, and renewable thanks to its biological nature.

Coffee can be added into cosmetic formulations in different forms including coffee extract, oil, and coffee powder. These forms of coffee can be obtained by dry or wet methods such as pulping, washing, fermentation, and polishing, depending on the level of process sustainability concerns and required bio-active compound types. Coffee beans have a rough and rigid texture characteristic, which requires several dry and mechanical methods such as peeling and grinding to process beans (Mendes dos Santos et al., 2016). Teluca, Lessonia, Biogründl, Aromatic Fragrances International, BotanicalsPlus, and BioOrganic Concepts are some of the suppliers that can be listed as coffee-based cosmetic material suppliers (© SpecialChem, 2023).

Recently, sustainable startups and projects have been working on using coffee grounds to produce fabric and packaging materials as sustainable options. S.Café ® is a product of Singtex company which process uses the coffee ground to produce fiber that is used in clothing, home furnishing, and activewear, due to its high level of biodegradability, fast-drying, elastic, odor-controlling, and UV protection properties (© SINGTEX, 2021; TextileMates, 2019).

Furthermore, coffee ground properties and physical characteristics also make it an appropriate material to produce bioplastics which can be an economically and environmentally sustainable option for packaging. By mixing coffee-based bioplastics with other traditional materials, more renewable and biodegradable packaging is produced by valorizing high amounts of coffee ground waste (Oliveira et al., 2021). These applications are already been used by several sustainable startup brands such as BeaNused and patents are pending to certify coffee use in bioplastic production (Huynh, 2023; BeaNused ®, 2023).

Compared to other biomaterials, coffee has higher CO2 and water footprint levels due to the requirement of more complex processing methods. The average carbon emissions that one kilogram of coffee bean production is around 15,3 kilograms, which is mainly emitted in the transportation stage of the life cycle (Nab and Maslin, 2020). On the other hand, one kilogram of coffee bean production requires around 16000 liters of water, which is also very high, especially when compared to other plant-based biomaterials (https://evgenii.com/water-footprint/en/). These numbers are the value for the production of one kilogram of green coffee beans, each added process may increase the water and CO2 footprint levels.

Material: Coffee			
Category:	Fruit/Plant-based	**Forms used (cosmetics):**	Coffee extract, oil, powder
Manufacturing Processes:	Pulping, washing, fermentation, polishing, peeling, grinding	**Producer Company Names:**	Teluca, Lessonia, Biogründl, Aromatic Fragrances International, BotanicalsPlus, BioOrganic Concepts
Application Areas:	Cosmetics, pharmaceuticals, textile, packaging		
Origin:		**End of Life:**	
Renewability	Yes	**Type of Recycling**	Upcycling
Recyclability	Yes	**Compostability**	Yes
By-product Availability	Yes (pulp, skin, bean, silverskin, parchment)	**Bioodegradability**	Yes
Source of Product	Bio-based	**Landfill**	Yes
Aesthetic Characteristics:		**Environmental Impact:**	
Texture	Rough (bean)	**Carbon (co2) Footprint (kg/kg prd.)**	15,3
Transparency	Matte (bean), transparent (oil)	**Highest impact stage:**	Transportation
Malleability	Rigid (bean), elastic (grounds)	**Water Footprint (lt/kg)**	16000

Table 9: Summary Table of Coffee Material Properties

4.2.10. Development Status of Cucumber

Cucumber is a plant-based material that has been used as a traditional beauty material for centuries, and being a bio-based material, it is highly present in formulations of different skin and hair care products. Being a fruit and plant-based, cucumber is highly biodegradable and compostable. While the consumption of cucumber is very high as a food source, a significant amount of waste is also created afterward, which leads to free available waste material that can be upcycled into cosmetics or pharmaceuticals raw biomaterials.

Each part and byproduct of cucumber is rich in water content and antioxidants, thus every part of the cucumber can be processed to be added into cosmetic formulations such as water, peel powder, seed oil, and fruit extract. Its smooth, soft, and elastic texture makes it easily transformable mechanically. These forms of cucumber can be obtained by mostly mechanical methods such as drying, grinding, juicing, and sometimes with the help of chemical or organic solvent processes such as solvent, glycol, and water extractions. An example list of supplier companies that sell cucumber-based skin and hair care biomaterials can be made of Sophim, LEV, Bioveda, Parnika, OQEMA, Symrise, BotanicalsPlus, Bio-nest and many others (© SpecialChem, 2023).

Compared to other mentioned plant-based biomaterials, cucumber has a relatively high carbon footprint of 2,2 kilograms per kilogram of fruit produced. The largest impact of these CO2 emissions belongs to the growing and farming stage of cucumbers, which is mainly caused by high maintenance needs and the amount of water used (Mersereau, 2023). Even though the carbon footprint is one of the highest compared to other materials, the water footprint of cucumber production is one of the lowest compared to other materials' water consumption, which is around 353 liters per one kg of cucumber produced (https://evgenii.com/water-footprint/en). Although its CO2 footprint is higher compared to other fruits, it is still lower than the emissions caused by coffee, tea, and animal-based materials, and cucumber still stands as a significantly sustainable material since it has been used and trusted for centuries, has less water consumption and is highly biocompatible and biodegradable.

Material: Cucumber			
Category:	Fruit/Plant-based	**Forms used (cosmetics):**	Fruit extract, juice, seed oil, peel powder
Manufacturing Processes:	Drying, grinding, juicing, mechanical or solvent extractions	**Producer Company Names:**	Sophim, LEV, Bioveda, Parnika, OQEMA, Symrise, BotanicalsPlus, Bio-nest
Application Areas:	Cosmetics, pharmacuticals, culinary		
Origin:		**End of Life:**	
Renewability	Yes	**Type of Recycling**	Upcycling
Recyclability	Yes	**Compostability**	Yes
By-product Availability	Yes (Peels, leaves, seeds)	**Bioodegradability**	Yes
Source of Product	Bio-based	**Landfill**	Yes
Aesthetic Characteristics:		**Environmental Impact:**	
Texture	Smooth	**Carbon (co2) Footprint (kg/kg prd.)**	2,2
Transparency	High	**Highest impact stage:**	Growing
Malleability	Elastic	**Water Footprint (lt/kg)**	353

Table 10: Summary Table of Cucumber Material Properties

4.2.11. Development Status of Eucalyptus

Eucalyptus is a plant that is used as a biomaterial in many industries due to its physical, chemical, and nutritional properties. Eucalyptus fibers and eucalyptus-based cosmetic materials such as oil and extracts are biodegradable and compostable, therefore making them preferable over chemical substitutes. Moreover, eucalyptus leaves are very suitable for upcycling eucalyptus plants into fabrics, thanks to their smooth, soft, and elastic texture. Thus, the textile industry is one of the main industries that eucalyptus is most developed as a biomaterial. Eucalyptus fiber, which is also called Tencel, is highly sustainable in terms of both materials and processes, creating an amazing opportunity for the textile industry (TENCEL™, 2023). Additionally, eucalyptus woods are very useful in furniture production, making eucalyptus a sustainable material option for that industry (Nguyen, n.d.).

Along with textile use, eucalyptus extract, and oils are also present in cosmetics and personal care products, even though there are not too many product types including eucalyptus in the market. Eucalyptus oil and extract for cosmetics can be acquired with several processes including microwave, steam, or ultrasound-assisted extraction, hydro-distillation, enzymatic extractions, and extraction with different organic solvents supercritical fluid extraction (Zhao and Zhang, 2014). These cosmetic biomaterial forms of eucalyptus can be extracted from plant leaves or their byproducts such as flowers, wood, stem, or pulp. Eucalyptus-based cosmetic materials are provided by various suppliers such as Bioveda, Carubba, Durae Corporation, BioOrganic, Provital, Vevy Europe and Symrise (© SpecialChem, 2023).

There is a lack of information in the literature explaining the carbon footprint caused by eucalyptus production or eucalyptus-based biomaterial processing in the cosmetics field. On the other hand, few sources are measuring the water footprint of eucalyptus production, in one of them implies one kilogram of eucalyptus production requires approximately 785 liters of water, which can be considered high when compared with some other plant-based biomaterials. Plus, it has been found in the past that eucalyptus can cause soil degeneration (Jaleta et al., 2016). All this information about eucalyptus plants shows that even though there are several drawbacks present, eucalyptus is a nonhazardous and sustainable biological material that can be used safely in cosmetic formulations. However, its applications in textiles, accessories, and furniture (from eucalyptus wood) are more developed, common, and suitable due to the plant characteristics and sustainability levels.

Material: Eucalyptus			
Category:	Plant-based	**Forms used (cosmetics):**	Eucalyptus extract and oil
Manufacturing Processes:	Microwave, solvents, enzyme, ultrasound-assisted extraction, hydro-distillation	**Producer Company Names:**	Bioveda, Carubba, Durae, BioOrganic, Provital, Vevy Europe, Symrise
Application Areas:	Cosmetics, textile, furniture		
Origin:		**End of Life:**	
Renewability	Yes	**Type of Recycling**	Upcycling
Recyclability	Yes	**Compostability**	Yes
By-product Availability	Yes (Leaves, pulp, wood, stem, flower)	**Bioodegradability**	Yes
Source of Product	Bio-based	**Landfill**	Yes
Aesthetic Characteristics:		**Environmental Impact:**	
Texture	Smooth	**Carbon (co2) Footprint (kg/kg prd.)**	N\A
Transparency	Medium	**Highest impact stage:**	N\A
Malleability	Elastic	**Water Footprint (lt/kg)**	785

Table 11: Summary Table of Eucalyptus Material Properties

4.2.12. Development Status of Fungi

Fungi are biological organisms that we can see in all areas of our lives, as their wide variety of forms and special characteristics of these fungi make them useful in many industries such as culinary, textile, packaging, and cosmetics. While fungi are mostly known as a food source, fungi, and mycelium are highly developed in fiber production in the textile industry (© Mylium B.V., 2022; Warner, 2020). This is due to the appropriate physical and mechanical properties of fungi mycelium, such as being soft, elastic, and antimicrobial. In addition to textiles, fungi mycelium is also used as a packaging material that can be used to substitute plastics, thanks to its same transformable texture (© Ecovative Design LLC, 2023; © Ekopak Limited, 2022). Being a biodegradable and compostable material, fungi-based packaging and textile biomaterials are highly sustainable and are preferred by producers who are conscious of environmental and economic sustainability.

In the cosmetics field, fungi use is less than textile and packaging industry since it is less developed. Fungi-based materials in cosmetics can be obtained by processing different type of fungi and their mycelium since these parts are rich in elements that are beneficial for skin health. Fungi can be transformed into cosmetic materials by applying heat treatments, grinding, chemical, and water solvent extractions to the mushroom plants or other forms of fungi. Macrocare Tech, Active Concepts, Dermalab, Arxada, Native Extracts, Morechem, Lvyin Biotech, and Carubba firms are some of the cosmetic material suppliers that have fungi extract and mycelium that can be added into cosmetic formulations (© SpecialChem, 2023).

Several forms of fungi exist and grow on their own, therefore, there is no intervention needed for them to be harvested and planted, which makes the overall process very low on carbon

emissions and water consumption. Since mushrooms, edible fungi, are one of the few forms that are planted and raised by people for culinary reasons, the carbon and water footprint related to fungi production is only relevant to edible mushrooms. These edible mushrooms and their mycelium can be used as cosmetic materials. For one kilogram of mushroom production, carbon emission is around 0,15 kilograms and water consumption is around 15 liters, which is very low compared to other biomaterials (Howart, n.d.; © The Mushroom Council, 2023). Hence, it is clear that fungi are an environmentally sustainable material, in addition to being economically sustainable, since the overall costs of fungi production are very low. Moreover, mycelium is known to be a carbon-negative element and just requires very little water to grow, which proves that mycelium is a very advantageous biomaterial that can be used in many sectors including cosmetics or textile (© MaterialDistrict, 2017; © Kleiderly GmbH, 2022).

Material: Fungi			
Category:	Biologic Organisms	**Forms used (cosmetics):**	Fungi extract, mycelium
Manufacturing Processes:	Heat treatments, grinding, chemical and water solvent extraction	**Producer Company Names:**	Macrocare Tech, Active Concepts, Dermalab, Arxada, Native Extracts, Morechem, Lvyin Biotech, Carubba
Application Areas:	Cosmetics, textile, packaging, culinary		
Origin:		**End of Life:**	
Renewability	Yes	**Type of Recycling**	Upcycling
Recyclability	Yes	**Compostability**	Yes
By-product Availability	Yes (mycelium)	**Bioodegradability**	Yes
Source of Product	Bio-based	**Landfill**	Yes
Aesthetic Characteristics:		**Environmental Impact:**	
Texture	Soft, smooth	**Carbon (co2) Footprint (kg/kg prd.)**	0,26
Transparency	Medium	**Highest impact stage:**	Growing
Malleability	Elastic	**Water Footprint (lt/kg)**	15

Table 12: Summary Table of Fungi Material Properties

4.2.13. Development Status of Honey

Honey is an animal-based biomaterial that is widely present in different cosmetics and personal care products such as haircare, skincare, and make-up products. Its pleasant smell and aroma, smooth and dense texture, and long-known safety for years make honey, making it biocompatible with the human body, a very desirable and suitable ingredient in the beauty sector. Being biologic by nature, honey is biodegradable, compostable, and recyclable for use in different areas, in case of wastes created after culinary uses (© citizensustainable.com, 2023). Unconsumed honey creates a significant opportunity for upcycling honey into cosmetics, personal care, and pharmaceutical formulations to capture the diverse benefits of honey to human health, especially for skin and hair.

Honey is extensively used in cosmetic formulations, mostly in its form as honey, but also in the forms of extracts or beeswax. To obtain these forms that are suitable for cosmetic applications, particular processes such as filtration, heat treatments (microwave or ultrasound) or straining may need to be applied, depending on the type of cosmetic product or target benefits, in addition to the traditional honey processing methods (Subramanian, Hebbar and Rastogi, 2007). After its processing or consumption by people, byproducts of honey such as flowers, jelly, pollen or beeswax may appear, which can also be used as a source of cosmetic biomaterial since these byproducts also contain beneficial bio-active compounds like honey itself. Some of the companies that supply honey-based cosmetic raw biomaterials can be exemplified as Carrubba, Dermalab, Akott, Marika Botanicals, Symrise, Biogründl, Morechem, AQIA, and Croda (© SpecialChem, 2023).

Honey is a product that has a very low impact on the environment because it is produced naturally in most cases. In the context of honey production and collection, the carbon footprint is very low, compared to other biomaterials mentioned in this research, which is around 1, 44 kilograms of GHG per one kilogram of honey production, with the most impactful stage of honey extraction in stationary conditions and hive management in migratory conditions (Pignagnoli et al., 2023; Giampieri et al., 2022). There is no information in the literature about the water footprint of honey production. Since honey is produced by bees naturally, without the need for further interventions by people such as fruit growing and harvesting, it is probably assumed that honey production does not require water consumption, with the neglect of further processes in the honey supply chain such as processing, packaging, or transport. The lack of information about the water footprint of honey production in general or its cosmetic formulation can be a new potential research area in the future.

To summarize, being bio-based, biodegradable, renewable, and biocompatible material, honey is a very appropriate and healthy material that is used in the cosmetics field, substituting many chemical ingredients. It is also environmentally sustainable since it has moderate impacts in terms of carbon emissions and water consumption, especially when compared to other animal-based biomaterials, chitin, coffee, or tea, validating its sustainability targets in general.

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Material: Honey			
Category:	Animal-based	**Forms used (cosmetics):**	Honey, extract, beeswax
Manufacturing Processes:	Microwave and ultrasound heating, filtration, straining	**Producer Company Names:**	Carrubba, Dermalab, Akott, Marika Botanicals, Symrise, Biogründl, Morechem, AQIA, Croda
Application Areas:	Cosmetics, pharmacuticals, culinary		
Origin:		**End of Life:**	
Renewability	Yes	**Type of Recycling**	Upcycling
Recyclability	Yes	**Compostability**	Yes
By-product Availability	Yes (pollen, beeswax, jelly, flower)	**Bioodegradability**	Yes
Source of Product	Bio-based	**Landfill**	Yes
Aesthetic Characteristics:		**Environmental Impact:**	
Texture	Smooth, dense	**Carbon (co2) Footprint (kg/kg prd.)**	1,44
Transparency	High	**Highest impact stage:**	Honey extraction, hive management
Malleability	N\A - Liquid	**Water Footprint (lt/kg)**	N\A

Table 13: Summary Table of Honey Material Properties

4.2.14. Development Status of Milk

Milk is an animal-based biomaterial that has been preferred as a natural source of beauty for centuries. Since it is a biological source, it is also biodegradable and compostable, which makes milk attractive for cosmetic producers who prefer natural materials in their products. Even though recently there have been concerns over animal-based products and cosmetic brands sometimes adding vegetal milk instead of animal milk, it is still known as an environmentally friendly and cost-effective biomaterial substituting synthetic hazardous chemicals in the beauty industry.

Milk is applied in cosmetic products in various forms including milk proteins, milk powder, and extract. Byproducts of milk such as buttermilk, whey, ghee, and skim milk can also be used to obtain milk proteins and extracts (Rafiq and Rafiq, 2019). Milk proteins are important for capturing the benefits of milk to the skin, so the processing of milk for cosmetic formulations should be conducted without losing the value of milk proteins. The most common processing methods of milk for cosmetic formulations are hydrolysis, fermentation, and enzyme, mechanical, and chemical extractions. Milk-based cosmetic materials are supplied from different material firms and some of these firms can be listed as Morechem, Hellenic Asinus Farms, Biogründl, Lipoid Kosmetik, Marika Botanicals, Teluca, Akott and Dermalab (© SpecialChem, 2023).

Milk is a product that has a moderate impact on the environment in the context of carbon emissions and water consumption. The CO2 footprint is around 1,5 kilograms of CO2 for cow milk and 1 kilogram of CO2 for goat milk, which is mostly released in the farming stage of the animals that produce milk (Balcha et al., 2022; Marie, 2023). There are lack of information

about the CO2 footprint of milk produced by other cattle animals, but it is considered as similar to the mentioned levels. The level of carbon emission of milk is higher than all fruit-based materials mentioned in their research but lower than tea and coffee. As for water footprint, one liter of milk production requires approximately 1020 liters of water, the type of dairy is not mentioned in the relevant source but is accepted as a general value for milk (Mekonnen and Hoekstra, 2010). This number of water consumption is higher than all the fruit-based biomaterials except coconut but lower than tea, coffee, olive, and cacao.

Material: Milk			
Category:	Animal-based	**Forms used (cosmetics):**	Milk, milk extract and powder, milk proteins
Manufacturing Processes:	Hydrolysis, fermentation, enyzme, mechanical and chemical extractions	**Producer Company Names:**	Morechem, Hellenic Asinus Farms, Biogründl, Lipoid Kosmetik, Marika Botanicals, Teluca, Akott, Dermalab
Application Areas:	Cosmetics, pharmaceuticals, culinary		
Origin:		**End of Life:**	
Renewability	Yes	**Type of Recycling**	Upcycling
Recyclability	Yes	**Compostability**	Yes
By-product Availability	Yes (buttermilk, whey, ghee, skim milk)	**Bioodegradability**	Yes
Source of Product	Bio-based	**Landfill**	Yes
Aesthetic Characteristics:		**Environmental Impact:**	
Texture	Smooth	**Carbon (co2) Footprint (kg/kg prd.)**	1,5
Transparency	Medium	**Highest impact stage:**	Farming
Malleability	N\A	**Water Footprint (lt/kg)**	1020

Table 14: Summary Table of Milk Material Properties

4.2.15. Development Status of Olive

Olive is a plant-based biomaterial that is commonly used for culinary purposes, mostly in the form of olive fruit and olive oil. Olive oil has several benefits to the overall health and skin, thus it is also used for cosmetic purposes and applied topically in addition to consumption as a food source. Being a highly biodegradable, renewable, compostable, and healthy bio-source, olive oil is preferred by many people for skin care instead of using chemical substances, that's the reason why olive oil-based cosmetics and personal care products are increasingly used. Various byproducts of olive oil production are also upcycled to obtain olive extracts for cosmetic products, such as olive seeds, leaves, and stems. In this way, olive wastes can also be valorized.

Olive oil is the most common form of olive used in cosmetics. Other than olive oil, olive seeds, leaves, and stems can be upcycled by several processing methods and extracts obtained from these parts can also become a part of cosmetic formulations. While virgin olive oil can be obtained by just mechanical methods such as pressing, olive oil and extract as cosmetic materials are mostly obtained by various methods such as enzyme, infrared, microwave,

ultrasound-assisted, and water extraction or grinding (Otero et al., 2021). Morechem, Teluca, Sophim, Berkem, Bio-Extracts, Gustav Heess, Esperis, AQIA, and Active Concepts are some of the olive-based biomaterial suppliers that provide olive oil and extract which is applicable for cosmetic products (© SpecialChem, 2023).

Olive fruit has a smooth and elastic texture, which makes it to be processed conveniently. On the other hand, the seed of the olive is rigid, which can be used to produce olive powder, which is a type of ingredient applicable to cosmetics (© Upcycled Beauty Ltd, 2022). Byproducts of olives such as leaves, seed, and wood are recycled and used for the production of fertilizers, pharmaceuticals, and energy sourcing, other than cosmetic areas (Espeso et al., 2021). However, there is a lack of research in the literature on olive and its byproducts are appropriate to be used as a textile material as other biomaterial mentioned in this paper.

Olive oil production leads to carbon emissions which is around 1, 5 kilograms of CO2 for one kilogram of olive oil production, which can change depending on the virginity level of oil obtained, and the most impactful stage in terms of CO2 emissions is the farming stage (International Olive Council, 2016). These numbers show the level of CO2 footprint of olive oil production is low when compared to other fruit-based and animal-based biomaterials. On the other hand, the water footprint of olive production is around 3000 liters per kilogram of olive, while this number increases to 14500 liters for olive oil production, which is quite high compared to other biomaterials that are used in cosmetic and personal care products (https://evgenii.com/water-footprint/en/).

Material: Olive			
Category:	Fruit/Plant-based	**Forms used (cosmetics):**	Olive extract, powder and oil
Manufacturing Processes:	Pressing, enzyme, infrared, microwave, ultrasound assisted, water extraction	**Producer Company Names:**	Morechem, Teluca, Sophim, Berkem, Bio-Extracts, Gustav Heess, Esperis, AQIA, Active Concepts
Application Areas:	Cosmetics, pharmaceuticals, culinary		
Origin:		**End of Life:**	
Renewability	Yes	**Type of Recycling**	Upcycling
Recyclability	Yes	**Compostability**	Yes
By-product Availability	Yes (Leaves, seed, pomace, stem)	**Bioodegradability**	Yes
Source of Product	Bio-based	**Landfill**	Yes
Aesthetic Characteristics:		**Environmental Impact:**	
Texture	Smooth	**Carbon (co2) Footprint (kg/kg prd.)**	1,5
Transparency	High (oil), matte (fruit)	**Highest impact stage:**	Farming
Malleability	Elastic (fruit), rigid (seed)	**Water Footprint (lt/kg)**	3000 (olive) - 14500 (olive oil)

Table 15: Summary Table of Olive Material Properties

4.2.16. Development Status of Pineapple

Pineapple is a tropical fruit that has various benefits to the health when consumed both as a fruit of topical application. More than half of the pineapple fruit consists of byproducts, which can be listed as core, leaves, skin, and root, therefore, these parts become wasted after consumption, which can be conveniently upcycled and used as sustainable materials for different industries. Being a plant-based biomaterial, pineapple is a biocompatible, biodegradable, renewable, compostable, and recyclable source that can be used as a harmless, both economically and environmentally sustainable material considering the valorization of the waste created by pineapple consumption.

Bromelain is the most important bioactive compound extracted from pineapple in the context of cosmetic formulations. Bromelain is extracted from almost all parts of the pineapple fruit and its byproducts such as peels, core, leaves, seeds, root, and crown, with several processing methods such as ultrasound-assisted, hydrothermal extraction, microwave-assisted, enzymatic, and solvent extraction (Rico et al., 2020). Pineapple-based materials in cosmetics can be in different forms such as fruit extract, pulp, powder, or juice. Supplier companies that serve cosmetic brands these pineapple-based materials can be exemplified as Quality Plus, Akott, Symrise, Bioveda, BioOrganic, DermaLab, Parnika, Apara, Kuber, Alfa Chemistry, ProVital and others (© SpecialChem, 2023).

The physical and mechanical properties of pineapple fruit and its elements make pineapple an appropriate material not just for cosmetics but also for textiles and other objects. The elastic, durable, strong, and water resistance capabilities of pineapple fibers make it a low-impact biomaterial that can be used for clothes, accessories, and objects. Moreover, the production process of these fibers mostly requires mechanical methods that can be considered sustainable. Pineapple fibers are increasingly used even by famous big or high-end brands as sustainable materials (©Ananas Anam, 2017; Rasmi, n.d.).

Pineapple is a fruit-based biomaterial that has a low impact on the environment when considering its CO2 and water footprint numbers. In pineapple production, the CO2 footprint is 0, 2 kilograms of CO2 for one kilogram of pineapple. This number is low compared to many other biomaterials that mentioned in this review such as banana, citrus, olive, coffee, and others. In its whole life cycle, the most impactful stage of pineapple in terms of carbon footprint is transportation, since pineapple can only be grown in tropical regions and has to be transported to other countries (Mersereau, 2023). As for water footprint, pineapple has also a relatively low

level of water consumption in the life cycle which is around 255 liters per kilogram of fruit produced (https://evgenii.com/water-footprint/en/). Of all biomaterials mentioned in this research, pineapple is the one that has the lowest level of water and CO2 footprint, which proves that pineapple is one of the most appropriate bio-based materials that can be used as a material in cosmetics, in terms of carbon and water footprint analysis.

Material: Pineapple			
Category:	Fruit/Plant-based	**Forms used (cosmetics):**	Fruit extract, pulp, juice, powder
Manufacturing Processes:	Ultrasound-assisted, hydrothermal extraction, microwave-assisted, enzymatic, solvent extraction	**Producer Company Names:**	Quality Plus, Akott, Symrise, Bioveda, BioOrganic, DermaLab, Parnika, Apara, Kuber, Alfa Chemistry, ProVital
Application Areas:	Cosmetics, textile, objects, packaging		
Origin:		**End of Life:**	
Renewability	Yes	**Type of Recycling**	Upcycling
Recyclability	Yes	**Compostability**	Yes
By-product Availability	Yes (Peels, core, leaves, seeds, root, crown)	**Bioodegradability**	Yes
Source of Product	Bio-based	**Landfill**	Yes
Aesthetic Characteristics:		**Environmental Impact:**	
Texture	Scaly (peel), rough (core & leaves), smooth (fruit)	**Carbon (co2) Footprint (kg/kg prd.)**	0,2
Transparency	Medium	**Highest impact stage:**	Transportation
Malleability	Medium (fruit), Elastic (leaves) Rigid (roots, core)	**Water Footprint (lt/kg)**	255

Table 16: Summary Table of Pineapple Material Properties

4.2.17. Development Status of Silk

Silk is an animal-based biomaterial that is obtained mostly from worms, insects, or spiders. Its particular characteristics and physical properties such as elasticity and softness make it an excellent material for the textile industry. As mentioned in previous sections, while it is mainly a raw material for the textile industry, due to its transformable structure and its valuable proteins that are rich in bio-active compounds, silk is also used in cosmetics and personal care formulations as a biomaterial, mostly by high-end or specialized beauty brands. Silk is a bio-based source, therefore it is also biodegradable, biocompatible, and compostable (Cao and Wang, 2009).

Silk is applied to cosmetic formulation in the forms of silk proteins and hydrolyzed silk, which can be extracted from silk or its byproducts such as sericin, pupae, and pupae oil (Javali et al., 2015). These silk biomaterials can be obtained by several processing methods including heat treatments, organic solvents, and enzymatic extractions. Some of the companies that are providing silk-based cosmetic biomaterials to beauty brands can be listed as Teluca, AQIA, Biogründl, Sinerga, I.R.A. Istituto Ricerche Applicate and Seiwa Kasei (© SpecialChem, 2023).

Silk use as a biomaterial is increasing in the cosmetics field, but there are still limited applications of it in markets and information in the literature. Therefore, available information regarding the environmental impact of silk production and its use in literature is only relevant to the textile industry. For one kilogram of silk production, approximately 2,5 kilograms of CO2 is released to the environment and around 1000 liters of water need to be used (Giacomin et al., 2017; Hardman, 2022). Additionally, one kilogram is silk is obtained from more than 6000 silkworms, which requires intense animal farming and thus extra costs. There are several concerns regarding cruelty while producing silk since there are many producers who cause worms to die while obtaining silk (Pilkington, 2022). Although silk is known to be healthy and biological, silk production is not considered sustainable due to high water and energy consumption while growing silkworms, the amount of silkworms needed, the extraction of silk, and the production of silk fibers (Nguyen, n.d.). In short, silk can be considered a sustainable material in terms of health, biological roots, and lack of chemical use in fiber production, but there are several doubts about its sustainability related to production, cost, and animal wellbeing.

Material: Silk			
Category:	Animal-based	**Forms used (cosmetics):**	Silk, silk proteins, hydrolized silk
Manufacturing Processes:	Organic solvents, enzymatic extraction, heat treatments	**Producer Company Names:**	Teluca, AQIA, Biogründl, Sinerga, I.R.A. Istituto Ricerche Applicate, Seiwa Kasei
Application Areas:	Cosmetics, textile, accessories		
Origin:		**End of Life:**	
Renewability	Yes	**Type of Recycling**	Upcycling & Downcycling
Recyclability	Yes	**Compostability**	Yes
By-product Availability	Yes (sericin, pupae, pupae oil)	**Bioodegradability**	Yes
Source of Product	Bio-based	**Landfill**	Yes
Aesthetic Characteristics:		**Environmental Impact:**	
Texture	Smooth, soft	**Carbon (co2) Footprint (kg/kg prd.)**	2,5
Transparency	Medium	**Highest impact stage:**	Sourcing & manufacturing silk
Malleability	Elastic	**Water Footprint (lt/kg)**	1000

Table 17: Summary Table of Silk Material Properties

4.2.18. Development Status of Snail Slime

Snail slime is an animal-based biomaterial that has been used as a natural source of beauty for decades. For years, snails have been used in beauty centers as a treatment method, but in recent years, their direct application in cosmetics and personal care products has been increasing. Snail slime is preferred as a cosmetic material since it is bio-based, nontoxic, and an overall healthy ingredient, in addition to being biodegradable and compostable, in terms of environmental sustainability. Snail slime is a natural secretion that can be upcycled in the context of cosmetic

and medical use. Moreover, it can also be downcycled for eco-friendly packaging production (Di Filippo et al., 2021).

Snail secretions in cosmetic products can be seen in mainly two forms, which are slime and mucus. These forms can be obtained naturally from snails without any intervention, but to speed up the extraction process and to be transformed for cosmetic formulations, snail secretions are processed in various ways such as low voltage electrification, solvent and mechanical extractions, or filtration. Several natural ingredient producers have been providing snail slime recently, and some of these brands are also producing cosmetic formulations or products themselves. These companies can be exemplified as Nume-Lab, Wonder Company, Morechem, Biogründl, and Gale & Cosm (© SpecialChem, 2023).

In terms of environmental impact, snail slime is a favorable material since its carbon emissions can be considered low, which is around 1,76 kilograms of CO2 emissions per one kg of snail secretion produced, with the most impactful stage of secretion extraction from animals (Novara et al., 2022). Water footprint information regarding snail slime production is not available in literature yet, which can be another topic that can be studied, but there is also no information claiming that snail farming or slime extraction uses high amounts of water. So, snail slime can be considered as an environmentally sustainable biomaterial option for cosmetics and personal care products. However, to respect sustainability overall, snail farming and secretion extraction processes should be carried out considering the well-being of animals and should be far away from cruelty.

Material: Snail Slime			
Category:	Animal-based	**Forms used (cosmetics):**	Slime, mucus
Manufacturing Processes:	Low voltage electrification, solvent and mechanical extractions, filtration	**Producer Company Names:**	Nume-Lab, Wonder Company, Morechem, Biogründl, Gale & Cosm
Application Areas:	Cosmetics, pharmaceuticals, packaging		
Origin:		**End of Life:**	
Renewability	Yes	**Type of Recycling**	Upcycling & Downcycling
Recyclability	Yes	**Compostability**	Yes
By-product Availability	No	**Bioodegradability**	Yes
Source of Product	Bio-based	**Landfill**	Yes
Aesthetic Characteristics:		**Environmental Impact:**	
Texture	Smooth, soft	**Carbon (co2) Footprint (kg/kg prd.)**	1,76
Transparency	High	**Highest impact stage:**	Secration Extraction
Malleability	N\A - Liquid	**Water Footprint (lt/kg)**	N/A

Table 18: Summary Table of Snail Slime Material Properties

4.2.19. Development Status of Tea

Tea is a plant that is commonly used as a bio-based material in cosmetic formulations due to its nature full of vitamins and antioxidants, but also for being highly biodegradable, compostable in nature, and renewable. Tea is produced in very high amounts in the world, with different forms including black, green, or other fruit teas. These high amounts of tea consumption leads to a high amount of waste and unused byproducts such as leaves and stem of tea trees. All these products are upcycled extensively to be used in different areas, and mostly as skincare ingredients.

Tea extract and tea tree oil are the most common ways to add tea to cosmetics and personal care products, in some occasions, tea can be used directly in the products too. Tea extraction and tea tree oil processing can be done with several methods such as organic solvents, microwave and ultrasound extraction, filtration, drying, or distillation, depending on the targeted bio-active compounds and product type (Vuong et al., 2010). Some of the suppliers that prepare and provide tea, tea extract, and tea tree oil for cosmetic brands can be exemplified as Naturalin, BotanicalsPlus, Provital, Carubba, Kaiwal Biotech, Active Concepts, Dermalab, Esperis, Green Angel, and Biocosmethic (© SpecialChem, 2023).

There are different scientific experiments and developments towards producing tea-based materials to be used in different sectors such as textile, and the most known project of producing fabric from tea belongs to Suzanne Lee. Fibers that consist of cellulose, which can be

produced from tea with developing processing methods, can be used as a biodegradable clothing and accessory material, which will be a more sustainable option than synthetic fibers and decrease the water consumption overall, which is very high in textile processes. The project is still in the development process and mass production from tea fabric is one of the targets that scientists have (Krishnamurthy, 2016; Iowa State University ScienceDaily, 2016).

Depending on the type of tea, the average carbon emissions one kilogram of tea causes is around 31,5 kilograms of CO2, which is the most impactful stage of human consumption, which can significantly be affected by the consumption habits of consumers (Pearce, 2022). Tea production also requires a high amount of water, which is around 10000 liters to produce one kilogram of tea (Low, 2018). These numbers show that tea is a product that has a relatively higher impact on the environment in terms of carbon emissions and water consumption. When compared with the other most relative materials, coffee, and tea cause higher carbon emissions but require less water use. Compared will all other materials, tea is seen as one of the most

impactful biomaterials in terms of CO2 and water footprint for each kilogram of product obtained. Since processing methods, other materials in cosmetic products, and the amount of biomaterial used in formulation depend on each, it may not be logical to say tea is not a sustainable source because it has higher CO2 and water footprint levels.

Material: Tea			
Category:	Plant-based	**Forms used (cosmetics):**	Tea extract, tea tree oil
Manufacturing Processes:	Organic solvents, microwave, ultrasound extraction, filtration, drying, distillation	**Producer Company Names:**	Naturalin, BotanicalsPlus, Provital, Carubba, Kaiwal Biotech, Active Concepts, Dermalab, Esperis, Green Angel, Biocosmethic
Application Areas:	Cosmetics, textile, accesories		
Origin:		**End of Life:**	
Renewability	Yes	**Type of Recycling**	Upcycling
Recyclability	Yes	**Compostability**	Yes
By-product Availability	Yes (Leaves, stem)	**Bioodegradability**	Yes
Source of Product	Bio-based	**Landfill**	Yes
Aesthetic Characteristics:		**Environmental Impact:**	
Texture	Smooth	**Carbon (co2) Footprint (kg/kg prd.)**	31,5
Transparency	Medium	**Highest impact stage:**	Consumption
Malleability	Elastic	**Water Footprint (lt/kg)**	10000

Table 19: Summary Table of Tea Material Properties

5. PATENTS AND CERTIFICATIONS

To understand the development of biomaterials in the cosmetics and personal care industry, it is important to evaluate the patents that have been released in these fields. In this section, patents and certifications related to the mentioned biomaterials in this research, their benefits to the health, skin, and hair, their use areas, how they are applied to cosmetics, processing methods, and their specific formulations of these biomaterials and combinations with other materials are examined. Patents have been collected from the ‘’Google Patents’’ search engine and patents released between the years 1980-2023 have been selected to be added into patents lists. A total of 219 patents have been selected as representatives to present in which areas and functions biomaterials have been patented. Keywords have been selected separately for each biomaterial, including the names of biomaterials, ‘’extracts’’, ‘’oil’’, specific processing methods of each biomaterial in cosmetics, and adding ‘’cosmetic applications’’ phrases for each material. Most of the patents found belong to companies or individuals, other than research institutes or universities, and mostly to Asian countries such as China and South Korea, which are leading countries in beauty sectors and traditional practices. Information related to patents such as patent number, the country they belong to, countries it is been valid for, and detailed information regarding the innovation of biomaterials can be seen in the following tables.

5.1. Patents of Related Biomaterials in Cosmetics Field

Patent Number	Country	Year	Patent Name	Applications	Details
CN105030587B	China	2015	A kind of anti-aging cosmetics containing marine algae extract and preparation method thereof	China	Formulation and perparation method of a cosmetic product including marine algae for skin aging
US20130287714A1	Germany	2012	Cosmetic and/or dermatological preparations containing extracts of snow algae	WW	Cosmeting formulation for skin protection using snow algae extract and its processing methods
US8206721B2	Switzerland	2012	Use of an extract from snow algae in cosmetic or dermatological formulations	EU, USA	Processing method of snow algae for topical applications in cosmetics and pharmaceuticals
CN104644511B	China	2015	The preparation method of cosmetic composition and its marine alga sun-prevention component	China	Preparation method of sun protection cosmetic formulation with marine algae extract
EP2026759B1	Iceland	2007	Pharmaceutical and cosmetic use of extracts from algae obtainable from saline hot water sources	EU	Cosmetic and medical application areas of algae extract from hot water sources, specialized for skin-aging
US5508033A	USA	1996	Utilization of algae extract for the preparation of pharmaceutical, cosmetic, food or agricultural compositions	USA	Use areas of algae with its anti-radical activity with a specific extraction method
WO2002080876A2	France	2002	Use of a phaeodactylum algae extract to promote the proteasome activity of skin cells	WW	Cosmetic compositon of a specific algae extract and its applications on skin aging and skin protection from lights
CN104224650B	China	2014	Large seaweed extract sunscreen skin care emulsion and preparation method thereof	China	Formulation of sun protection cosmetics from seaweed extracts, for skin whitening, moisturizing and skin aging
WO2007078056A1	South Korea	2006	Cosmetic composition containing algae extract for effect on improving the skin complexion	WW	Skincare formulation from algae extract for improving skin clearness, color and skin aging
WO2011096628A1	South Korea	2011	Method for preparing uv screening nontoxic extract from red algae, and nontoxic sunscreen using same	WW	Formulation of a non-toxic sunscreen from red algae extract
KR100889973B1	South Korea	2007	Effect of antioxdant, wrinkles protection, antibacterial, anti-inflammatory and whitening from Tetraselmis suecica extract	South Korea	Cosmetic formulation from micro green algae and its benefits to the skin
CN107468552A	China	2017	A kind of cosmetics containing snowy algae extract	China	Use areas of micro snow algae extract in cosmetics, effects in skin aging
EP1433463B1	Japan	2003	Use of algal proteins in cosmetics	WW	Cosmetic uses of algae and its hydrolyzed proteins
WO2014131971A1	France	2014	Cosmetic composition containing a brown alga extract, a yeast extract and ascorbic acid	WW	Cosmetic formulation including brown algae for skin aging

Table 20: Patents applications for Algae use in cosmetics field

Patent Number	Country	Year	Patent Name	Applications	Details
WO2015158555A1	USA	2015	Aloe vera extract for personal care compositions	WW	Compostion and fraction of aloe vera extracts for skin and hair care formulations
KR20140143940A	South Korea	2013	Baby aloe vera shoot extract for preventing or treating skin aging	South Korea	Cosmetic compostion of aloe vera extract for skin aging
DE102010030654A1	Germany	2010	Cosmetic composition based on aloe vera and its use	Germany	Cosmetic compostion with aloe vera that is applicable for skin and hair
WO1993011780A1	USA	1992	Skin therapeutic mixture containing cold-processed aloe vera extract, with yellow sap and aloin removed	WW	Formulation and specific processing method of aloe vera for thrapeutic skincare
KR101651321B1	South Korea	2014	Anti-aging and Enhancing Skin Barrier Function composition for skin external application comprising Aloe vera Placenta Cell Culture Extract	South Korea	Cosmetic formulation with aloe vera extract for skin protection and aging
US4627934A	USA	1985	Single phase clear liquid after-shave treatment product containing aloe vera	USA	Cosmetic formulation with aloe vera extract for skin treatment
BR102020018678A2	Brazil	2020	Antioxidant cosmetic with levana, avocado oil and aloe vera extract	Brazil	Formulation of a facial biocosmetic product with aloe vera extract
EP3622946B1	France	2019	Cosmetic hair composition made of aloe vera and coconut oil and method for preparing same	EU	Hair care formulation with aloe vera extract
WO2022250313A1	South Korea	2022	Composition for moisturizing skin, promoting skin regeneration, and treating wounds, comprising aloe vera flower extract, or aloe vera flower extract and aloe vera polysaccharides, as active ingredient(s)	WW	Cosmetic compostion with aloe vera for skin moisturizing and regeneration
CN109381407A	China	2018	One kind is releived anti-ageing Aloe Vera Gel of moisturizing and preparation method thereof	China	Formulation and processing of a moisturizing gel based on aloe vera extract
KR102563734B1	South Korea	2022	Composition for wound treatment or skin regeneration containing Aloe vera flower extract and Aloe vera polysaccharide as active ingredients	South Korea	Cosmetic formulation with aloe vera extract for skin regenaration
KR20210100495A	South Korea	2020	Eco-friendly hand-disinfectant composition for helping skin-moisture containing extracts of aloe vera	South Korea	Cosmetic formulation using aloe vera extract as moisturizing agent
EP0919220A3	Canada	1998	Hair and skin treatment product containing aloe vera extract	EU, USA, Canada	Cosmetic formulation with aloe vera extract applicable to skin and hair
KR102435602B1	South Korea	2020	Cosmetic composition for skin improvement containing aloe vera adventitious root extract	South Korea	Cosmetic compostion of aloe vera extract for skin aging and whitening
JP4027949B2	Japan	2005	Hair nourishing agent	Japan	Hair care formulation with aloe vera extract for hair growth, dandruff and nourishment

Table 21: Patents applications for Aloe Vera use in cosmetics field

Patent Number	Country	Year	Patent Name	Applications	Details
KR101574199B1	South Korea	2015	Cosmetic composition with the rose banana fruit extract	South Korea	Cosmetic formulation with banana extract to help skin moisturizing, barrier protection, whitening and skin aging
ES2647621T3	Spain	2012	Cosmetic composition comprising banana, lotus and clover serum fractions	WW	Cosmetic formulation with banana for prventing skin pigmentation
TWM447138U	Taiwan	2012	Facial mask containing banana peel extract	Taiwan	Cosmetic fomulation with banana extract for skin repair
US6013260A	USA	1999	Banana peel extract composition and method for extraction	WW	Extraction and cosmetic formulation of banana peel for healing wrinkles and sunburn
FR2962330A1	France	2010	Cosmetic use of an extract of banana	France	Cosmetic formulation of banana extract to fight skin aging
FR3034663A1	France	2015	Cosmetic use of banana extract to depigmate the skin	France	Cosmetic formulation with banana extract and byproducts for skin pigmentation and whitening
FR3034668A1	France	2015	Cosmetic use of banana extract for its soothing effect	France	Cosmetic formulation with different banana peel extracts for skin soothing and inflmmation
EP3977980A1	South Korea	2016	Composition, for improving skin and preventing hair loss, comprising plant extract-derived extracellular vesicles	WW	Cosmetic compositon with banana tree extract for skin aging
KR20150120571A	South Korea	2014	Composition for improving condition of scalp and hair containing the extract of Banana leaf or Banana flower as active ingredient	South Korea	Hair care formulation with banana leaf and flower extract
KR102072990B1	South Korea	2019	Functional cosmetic compositions comprising complex extract of gold kiwi peel and banana peel as effective ingredient, and manufacturing method thereof	South Korea	Cosmetic compositon with banana peel extract for skin aging, sebum reduction, moisturizing
KR20230011778A	South Korea	2021	Composition for skin anti-pollution containing banana peel extract as an active ingredient	South Korea	Cosmetic compositon with banana peel extract for skin aging and protectant
CN115105456A	China	2022	Method for preparing sun-screening gel by combining extracts of banana peel, tangerine peel and shaddock peel and sun-screening gel	China	Sunscreen formulation with banana peel extract
TH18011A3	Thailand	2019	Eye care products mixed with banana peel extracts, jasmine water.	Thailand	Eye care formulation with banana peel extract

Table 22: Patents applications for Banana use in cosmetics field

Patent Number	Country	Year	Patent Name	Applications	Details
KR102130571B1	South Korea	2018	Low irritating cosmetic composition for skin whitening comprising albutin and extract of Euterpe oleracea fruit	South Korea	Cosmetic formulation with blueberry extract for skin whitening and soothing
KR20070071416A	South Korea	2005	Anti inflammatory cosmetic composition containing extract of blueberries	South Korea	Cosmetic cream, lotion, gel formulation with blueberry extract
KR20160096839A	South Korea	2015	Nourising cream containing blueberry extract collected in hydrogel	South Korea	Formulation of cosmetic hydrogel with blueberry extract
WO2023052479A1	France	2022	Use of a blueberry extract to improve the aesthetic appearance of skin	WW	Method and formulation of blueberry powder for skin perfection
CN106389195A	China	2016	Blueberry moisturizing and hydrating facial mask and preparation method thereof	China	Cosmetic formulation with blueberry extract for skin conditioning and elasticity
KR102283096B1	South Korea	2020	Composition for prevention or improvement skin inflammation induced by particlulate matter containing fermented blueberry and black rice extracts	South Korea	Cosmetic formulation of blueberry extract for preventing inflammation
KR20180112284A	South Korea	2017	Cosmetic composition containing Damask rose flower and blueberry extracts	South Korea	Cosmetic formulation with blueberry extract for skin aging and whitening
CN107456423A	China	2017	A kind of blueberry freckle-removing beauty cream and preparation method thereof	China	Cosmetic formulation with blueberry extract for skin repair, nourishment
WO2006075865A1	South Korea	2006	Skin-condition improving composition comprising vaccinium uliginosum extract and method for preparation thereof	WW	Formulation and processing method of blueberry for skin conditioning, aging, whitening
KR101449026B1	South Korea	2008	Hair cosmetic composition for hair anti-aging effects	South Korea	Hair care formulation with blueberry extract for hair quality
AU2021102391A4	Australia	2021	A Blueberry Moisturizing and Hydrating Facial Mask and Its Preparation Method	Australia	Cosmetic formulation with blueberry for skin moisturizing and brightening

Table 23: Patents applications for Blueberry use in cosmetics field

Patent Number	Country	Year	Patent Name	Applications	Details
WO2010048686A1	Brazil	2010	Antioxidant complex, cosmetic and pharmaceutical compositions containing said complex, and use thereof	WW	Cosmetic formulation of cacao extracts for skin protection and repair
WO2006117465A2	France	2006	Use of cocoa polyphenols to regulate skin pigmentation	WW	Novel formulation of cacao extracts for preventing skin pigmentation
WO2001095872A1	France	2001	Cosmetic and/or dermatological composition based on cocoa extracts	WW	Topical cosmetic formulation of cacao extracts for skin aging
EP2148648B1	USA	2008	Personal care composition with cocoa butter and dihydroxypropyl amonium salts	US, EU	Cosmetic formulation including cacao butter for preventing skin color
WO2001082889A1	Great Britain	2001	Cosmetic lotions comprising cocoa butter	WW	Cosmetic lotion formulation with cacao butter as moisturizer
WO2017157998A1	France	2017	Peptide and saccharide hydrolysate of cocoa beans, cosmetic compositions containing same, and cosmetic uses of same	WW	Processing and preparation of cocoa bean extracts for sun protection and skin aging
KR101836348B1	South Korea	2017	Method for production of cacao nibs extract and cosmetic composition thereof	South Korea	Extraction method and cosmetic composition for cocoa beans to fight skin aging
WO2019122780A1	France	2018	Make-up composition comprising a hydrolysate of theobroma cacao l beans and at least one prebiotic and a probiotic	WW	Cosmetic formulation of cacao bean extracts as make-up agents

Table 24: Patents applications for Cacao use in cosmetics field

Patent Number	Country	Year	Patent Name	Applications	Details
WO1999049878A1	USA	1999	Skin lightening composition containing magnesium ascorbyl phosphate and uninontan-u34tm (extract formulation of cucumber extract and lemon extract)	WW	Cosmetic formulation with lemon extract for skin lightening
KR20150139688A	South Korea	2014	The Extract Of The Citrus grandis Osbeck Having Skin Whitening Activity And Cosmetic Composition Containing The Same	South Korea	Cosmetic formulation with citrus extract for skin lightening
WO2006102289A2	USA	2006	Skin lightening compositions	WW	Cosmetic formulation with lemon extract for skin lightening
CN108542819B	China	2018	A kind of biology skin lightening facial mask liquid and preparation method thereof	China	Cosmetic formulation with orange peel extract for skin lightening
CN108619033B	China	2018	Whitening skin-care essence with synergistic whitening effect and preparation method thereof	China	Cosmetic formulation with citrus extract for skin whitening
EP3331617B1	France	2017	Exfoliating cosmetic composition including pieces of candied citrus fruit	WW	Cosmetic exfoliating agent, processing and formulation of citrus peels
WO2004091569A2	USA	2004	Activated citrus peel extract	WW	Activation and processing method for citrus fruits to be used in cosmetics
KR100858059B1	South Korea	2006	Preparing method of diosmetin from lemon peel and the cosmetic composition containing thereof as active ingredient	South Korea	Extraction of active agents from lemon peels to be used for skin aging
US5916576A	USA	1997	Method of scavenging free radicals using orange extract	WW	Processing method of orange for skin care formulation
CN106943324A	China	2017	One kind is dispelled orange peel line cosmetic composition	China	Processing method and formulation of orange peel for skin tightness
US20050079236A1	USA	2004	Citrus-derived cosmetic and medicinal composition, and nutritional food ingredient and associated methods of application	USA	Processing method of citrus peels to obtain stable cosmetic ingredients
JPH08295621A	Japan	1995	Cosmetic containing extract of citrus fruits	Japan	Cosmetic formulation of citrus extracts as antiseptic agents
US7291351B2	USA	2004	Citrus-derived cosmetic and medicinal composition and associated methods	USA	Cosmetic formulation of a citrus-based cream

Table 25: Patents applications for Citrus use in cosmetics field

Patent Number	Country	Year	Patent Name	Applications	Details
EP0965330B1	Germany	1999	Cosmetic and dermatolic compositions containing chitosan and phospholipids	WW	Cosmetic formulation with chitosan to protect skin barrier
KR20140113615A	South Korea	2014	A diy mask pack using chitosan and a preparation method thereof	South Korea	Cosmetic formulation with chitosan for exfoliating, moisturizing, skin barrier protection
CN105560160B	China	2016	A kind of facial mask liquid and preparation method thereof containing chitosan	China	Cosmetic formulation with chitosan for skin aging and moisturizing
WO2010086754A2	Germany	2010	Cosmetic or dermatological preparation comprising collagen, chitosan, glycosylaminoglycan and cell growth promoting peptide and/or cellular complex	WW	Cosmetic formulation with chitosan for skin cell growth
US4923977A	USA	1987	Cosmetic composition based upon N-hydroxypropylisopropylether chitosans as well as new N-hydroxypropylisopropylether derivatives of chitosan	WW	Cosmetic formulation with chitosan for hair and skin treatment
WO2015174772A1	South Korea	2015	Skin lifting cosmetic composition containing chitosan having fast dissolving property	WW	Cosmetic formulation and application method of chitosan for skin lifting
KR20190074157A	South Korea	2017	Composition for improving skin condition comprising chitosan as a effective ingredient and method for preparing the same	South Korea	Cosmetic formulation with chitosan for exfoliating, moisturizing, protection
KR101838404B1	South Korea	2016	Composition for preventing or treating Acne containing oligo-chitosan as an effective component	South Korea	Cosmetic formulation with chitosan for acne treatment
JP3253982B2	Japan	1991	Acne cosmetics	Japan	Cosmetic formulation with chitosan for acne treatment
WO2021150027A1	South Korea	2021	2-part skincare formulation	WW	Cosmetic formulation with chitosan for exfoliating, moisturizing, skin barrier protection

Table 26: Patents applications for Chitin use in cosmetics field

Patent Number	Country	Year	Patent Name	Applications	Details
US20190083370A1	USA	2016	Water-in-oil microemulsions for personal care	WW	Hair care cosmetic formulation with coconut oil
WO2009032146A1	USA	2008	Hair texturizer and conditioner	WW	Hair care cosmetic formulation with coconut oil
WO2001037792A2	France	2000	Cosmetic skin care composition comprising inter alia rice starch, coconut oil and karite butter	WW	Cosmetic formulation with coconut oil for skin aging
US9333164B1	USA	2015	Cosmetic composition having pomace olive oil	USA	Cosmetic formulation with coconut oil can be applied to skin and hair
KR102118974B1	South Korea	2018	Coconut oil, and the uses thereof	South Korea	Cosmetic formulation with coconut oil for skin moisturizing and whitening
US10434055B1	USA	2019	Modeling composition containing coconut oil	USA, South Korea, Japan	Cosmetic formulation with coconut oil for skin moisturizing
WO2017158014A1	France	2017	Coconut shell extracts, compositions containing same and uses	WW	Cosmetic use and composition of coconut shell extracts
CN109771339B	China	2019	Preparation method of coconut oil nano-emulsion with whitening and moisturizing effects	China	Processing method of coconut oil for skin whitening and moisturizing agents
CN103520045A	China	2013	Coconut oil emulsion shampoo	China	Hair care cosmetic formulation with coconut oil
US20160346192A1	USA	2015	Natural skin-care serum	USA	Cosmetic formulation with coconut oil for skin aging and moisturizing

Table 27: Patents applications for Coconut use in cosmetics field

Patent Number	Country	Year	Patent Name	Applications	Details
CN1980635A	China	2004	Coffee fruit cosmetic composition and method	China	Cosmetic formulation with coffee extract for anti-aging, moisturizing, skin lightening
KR101925585B1	South Korea	2017	Cosmetic composition comprising fermented extracts of green coffee beans	South Korea	Cosmetic formulation with coffee extract for skincare and hair care applications
KR20120073886A	South Korea	2010	A cosmetic composition containing coffee powder	South Korea	Cosmetic formulation in the form of solution with coffee extract
WO1998051263A1	USA	1998	Cosmetic compositions containing a coffee extract pigment	WW	Cosmetic formulation of coffee extract for make-up applications
KR20030011753A	South Korea	2002	Cosmetic preparation method by adding and extracting coffee extract (concentrate) or fine powder of coffee	South Korea	Cosmetic formulation with coffee extract and powder for acne prevention and sebum balancing
WO2004054534A1	France	2003	Use of an extract of decaffeinated coffee beans in the preparation of a composition intended to correct or prevent the disorders associated with a greasy skin by topical administration	WW	Cosmetic formulation with coffee extract and powder for sebum balancing
JPS62221609A	Japan	1986	Coffee-containing cosmetic	Japan	Processing method and cosmetic formulation of coffee bean extract as scrub
WO2015184494A1	Australia	2015	Process for preparation of caffeine extract	WW	Processing method of caffeine compounds for cosmetic use
KR20200011781A	South Korea	2018	Cosmetic composition for improving the health of scalp comprising natural caffeine and chlorogenic acid	South Korea	Cosmetic formulation with coffee extract for skincare and hair care applications
KR20210096018A	South Korea	2021	Whitening improvement functional cosmetics having fermented coffee beans	South Korea	Cosmetic formulation with coffee extract for skin whitening
KR100955389B1	South Korea	2009	Cosmetic composition for pore-minimizing and inhibition of sebum secretion containing natural materials	South Korea	Cosmetic formulation with coffee extract applicable for cleansers, lotions, creams
KR20180054072A	South Korea	2016	Cosmetic compositions comprising silver skin extracts of coffee beans	South Korea	Cosmetic formulation with coffee silverskin extract for skin aging and elasticity
WO2005102373A2	USA	2004	Coffee cherry cosmetic compositions and methods	WW	Processing and formulation of coffee cherry for cosmetic uses

Table 28: Patents applications for Coffee use in cosmetics field

Patent Number	Country	Year	Patent Name	Applications	Details
KR101105472B1	South Korea	2019	Cream Type Cosmetic Composition Comprising Cucumber and Preparation method thereof	South Korea	Cosmetic formulation with cucumber extracts for cleansing, regenerating and whitening skin
CN111494281A	China	2020	Skin-care cosmetic capable of whitening skin, removing freckles and protecting skin and preparation method thereof	China	Cosmetic formulation with cucumber extracts for skin cleansing and whitening
KR102262362B1	South Korea	2014	Composition for improving skin conditions comprising an extract of oriental melon stem or cucumber stem	South Korea	Cosmetic formulation with cucumber stem extracts for skin healing and whitening
WO2021149880A1	South Korea	2020	Compositions for promoting hair growth or preventing hair loss comprising a complex extract of cucumber, eggplant and snail	WW	Hair care cosmetic formulation for hair growth
KR20090055309A	South Korea	2007	A cosmetic composition for skin whitening and treating wrinkles	South Korea	Cosmetic formulation in different forms with cucumber extracts for skin pigmentation and aging
KR102142320B1	South Korea	2013	A method of extracting natural ingredients of cucumber and cosmetic composition comprising the extracted ingredients	South Korea	Processing method and formulation of cucumber extract for cosmetic use
KR101326556B1	South Korea	2013	Cosmetic composition for ultraviolet-proof containing the extract of sanguisorba officinalis and v. linariaefolia	South Korea	Cosmetic formulation with cucumber extracts for sun protection
CN103315936A	China	2013	Cucumber toner	China	Cosmetic formulation with cucumber extracts for cleansing, moisturizing and whitening skin
KR20220082192A	South Korea	2020	Cosmetic composition for anti-oxidation, skin whitening, and improving of skin wrinkle containing Sanguisorba officinalis extract	South Korea	Cosmetic formulation with cucumber extracts for skin aging and whitening
FR2886546A1	France	2005	Cosmetic or pharmaceutical composition, useful as a slimming agent to treat obesity, to prevent or treat the cellulitis and/or orange skin and/or to refine the figure or the face, comprises vegetable e.g. Hedera helix extract	WW	Cosmetic composition including cucumber extracts to heal skin tissue and cellulite
CN104257551A	China	2014	Cucumber juice moisturizing cream	China	Cosmetic formulation with cucumber extracts for skin moisturizing
CN101164521A	China	2006	Cucumber skin lotion dew and making method thereof	China	Processing and formulation of cucumber extracts for cosmetic lotion

Table 29: Patents applications for Cucumber use in cosmetics field

Patent Number	Country	Year	Patent Name	Applications	Details
CN109602652A	China	2018	Hair care strengthen the hair composition, hair soap and preparation method thereof	China	Cosmetic formulation with eucalyptus oil and extract for hair growth
KR102413205B1	South Korea	2022	Cosmetic composition for skin moisturizing, soothing, anti-inflammation, skin cell regeneration and anti-wrinkle containing Perilla Frutescens exosome, Eucalyptus Globulus exosome	South Korea	Cosmetic formulation with eucalyptus extract for skin moisturizing and aging
KR102183480B1	South Korea	2020	Composition for Improving Skin Conditions with Anti-Wrinkling, Antioxidant, Moisturizing, and Skin Cell Regeneration Property Comprising Complex Extract of Eucalyptus globulus, Lycium chinense, and Betula platyphylla as Active Ingredient	South Korea	Cosmetic formulation with eucalyptus extract for skin moisturizing and aging
KR20170120952A	South Korea	2016	Composition for preventing or improving skin wrinkle comprising Eucalyptus globulus extract treated by enzyme as active ingredient	South Korea	Cosmetic formulation with eucalyptus extract and bioactive compounds for skin aging
KR101274583B1	South Korea	2010	Composition for preventing hair loss and the preparation method thereof	South Korea	Cosmetic formulation with eucalyptus oil and extract for hair growth and care
KR20120069407A	South Korea	2010	Composition for preventing hair loss and the preparation method thereof	South Korea	Cosmetic formulation with eucalyptus oil and extract for hair growth and care
KR20170031386A	South Korea	2015	Cosmetic Composition Containing the Mixed Extract of Eucalyptus Globulus Leaf and Trifolium Pratense Leaf	South Korea	Cosmetic formulation with eucalyptus leaf extract for general skin care

Table 30: Patents applications for Eucalyptus use in cosmetics field

Patent Number	Country	Year	Patent Name	Applications	Details
US5980875A	USA	1999	Honey Preparations	USA	Formulation method for topical application of honey for hair growth, acne and wound healing
WO2004000339A1	Netherlands	2003	Honey-Based Skin Care Preparation	WW	Formulation method of honey in a gel-based form for skincare
KR101997231B1	South Korea	2019	Cosmetic composition containing enzyme-treated honey extract	South Korea	Enzymatic extraction method of honey that increases its exfoliating, moisturizing, whitening, wrinkle and skin tone improving effect
WO2018115487A1	France	2017	Cosmetic composition comprising an albizzia julibrissin extract, a rosemary extract and royal jelly	WW	Cosmetic formulation including royal jelly for skin healing and regeneration
FR3096262A1	France	2019	Forest honey from Ikaria Island as an anti-aging active	France	Cosmetic method to extract active ingredients from honey to prevent skin-aging
RU2221546C1	Russia	2002	Cream for hand named "milk and honey"	Russia	Formulation of a mositurizing and healing hand cream using honey extract
KR20120095049A	South Korea	2012	Cosmetic composition for skin whitening	South Korea, Japan, USA	Cosmetic formulation of skin whitening and skin tone protection including honey extract
RO129701A0	Romania	2013	Apibalm based on honey, propolis, bees wax and essential oils, for lips	Romania	Natural lip balm formulation from beeswax, honey and propolis
FR3096261A1	France	2019	Summer honey from the Åland archipelago as an anti-aging active	France	Cosmetic process to extract active ingredients from honey to prevent skin-aging
WO2014094377A1	China	2014	Bee venom composition with effects of protecting and beautifying lip	WW	Extraction method and cosmetic formulation of bee venom for lips protection
FR2977491A1	France	2011	Cosmetic Composition Comprising A Mixture of Honey	France	Cosmetic formulation including acacia honey, orange honey and thyme honey for skin barrier protection and moisturizing
WO1999036052A1	France	1999	Mixture containing honey, at least one essential oil and/or at least one essential oil derivative	WW	Compostion of honey and essential oils for cosmetics and pharmaceutical applications
CN112826785B	China	2015	Cosmetic skin care product comprising honey extract and use thereof	WW	Formulation of skin care product including honey extract with MMP inhibition
KR100795877B1	South Korea	2006	Cosmetic composition containing Honey Extract and Pumpkin Extract for moisturizing the skin	South Korea	Composition of cosmetics including honey extract for moisturizing skin caused by aging
KR19980077876A	South Korea	1997	Cosmetic composition containing honey extract or soy extract	South Korea	Skin conditioning formula including honey extract used as lotion, cream, makeup base, foundation
KR101884660B1	South Korea	2018	Cosmetic composition containing the enzymatic extracts of natural substances comprising propolis, royal jelly and honey	South Korea	Cosmetic composition of honey and byproducts as moisturizer and anti-inflammation agent

Table 31: Patents applications for Honey use in cosmetics field

Patent Number	Country	Year	Patent Name	Applications	Details
CN101664373A	China	2008	Donkey milk cosmetic and preparation method thereof	China	Cosmetic formulation with donkey milk for skin moisturizing, whitening and healing imperfections
CN104434729A	China	2014	Anti-cracking mare milk foot cream	China	Cosmetic formulation with horse milk for cracks and dryness
CN1275374A	China	1999	Fermented horse milk cream preparation	China	Cosmetic formulation with horse milk for moisturizing and light protection
DE19922932B4	Germany	1999	Cosmetic preparation and process for its preparation	Germany, France	Cosmetic formulation with donkey milk for skin tightening and aging
CN107929216A	China	2018	A kind of manufacture method of donkey milk freeze-dried powder facial mask, manufacture system and donkey milk freeze-dried powder facial mask	China	Cosmetic formulation with donkey milk applied to facial masks
WO2000016637A1	USA	1999	Dairy product and process for making	WW	Dairy processing method and formulation for cosmetic applications
CN108938532A	China	2018	A method of serial cosmetics are prepared using donkey milk	China	Cosmetic formulation with donkey milk for skin moisturizing, aging and healing imperfections
CN112535655A	China	2021	Cosmetic composition containing donkey milk and cosmetic containing composition	China	Cosmetic formulation with donkey milk for skin moisturizing, whitening and aging
KR102015180B1	South Korea	2017	Cosmetic composition comprising the fermented milk-cream broth of lactic acid bacteria	South Korea	Cosmetic formulation with milk and cream bioactive compounds for skin aging
CN109276456A	China	2018	A kind of donkey milk facial mask and its preparation process with skin whitening, moisturizing effect	China	Cosmetic formulation with donkey milk for skin moisturizing and whitening
WO1989005136A1	Switzerland	1988	Cosmetic products containing milk constituents	WW	Cosmetic soap formulation with milk proteins

Table 32: Patents applications for Milk use in cosmetics field

Patent Number	Country	Year	Patent Name	Applications	Details
KR101889471B1	South Korea	2015	Cosmetic composition containing Butea monosperma fermented extracts	South Korea	Cosmetic formulation including fungi mycelium for skin aging
KR101214872B1	South Korea	2010	Cosmetic composition containing Mycelial Culture Broth of Mushrooms	South Korea	Cosmetic formulation including fungi mycelium for skin aging, moisturizing
KR102550653B1	South Korea	2022	Cosmetic composition for anti oxidant and cell protection containing mushroom complex	South Korea	Cosmetic formulation including fungi mycelium for skin soothing
KR101772614B1	South Korea	2017	Cosmetic composition with the product fermented by Tremella fuciformis mycelium on medium with endothelial growth factor	South Korea	Cosmetic formulation including fungi mycelium for skin moisturizing and whitening
US6645502B2	USA	2001	Anhydrous cosmetic compositions containing mushroom extract	USA	Cosmetic formulation including different fungi extracts for healing skin imperfections and aging
KR19980038284A	South Korea	1996	Cosmetic composition having an anti-aging effect of skin containing extracts of the situation mycelium	South Korea	Cosmetic formulation including fungi mycelium for skin aging
KR101266528B1	South Korea	2010	Moisturizing and/or whitening cosmetic composition comprising polysaccharide extracted from Lentinus edodes mycelium culture product	South Korea	Cosmetic formulation including fungi mycelium for skin moisturizing and whitening
CN102743321A	China	2011	Application of bamboo fungus in cosmetics	China	Cosmetic formulation including fungi extract for skin moisturizing
KR20170005534A	South Korea	2015	The Cosmetic composition containing the culture medium of mycelium from Elfvingia applanata using natural medium	South Korea	Cosmetic formulation including fungi extract for skin moisturizing, whitening and acne prevention
KR102111882B1	South Korea	2019	Cosmetic composition containing mushroom complex	South Korea	Cosmetic formulation including fungi mycelium for skin aging and moisturizing
KR100848515B1	South Korea	2008	Cosmetics for whitening compring mushroom fermentation as an effective ingredient	South Korea	Cosmetic formulation including fungi mycelium for skin whitening

Table 33: Patents applications for Fungi use in cosmetics field

Patent Number	Country	Year	Patent Name	Applications	Details
US9333164B1	USA	2015	Cosmetic composition having pomace olive oil	USA	Cosmetic formulation with olive oil as skin moisturizer
KR101133067B1	South Korea	2005	Cosmetic formulation of a W/O/W multiple emulsion containing olive oil by one-step process	South Korea	Processing method and formulation of olive oil to be applied in cosmetics
EP1561457B1	USA	2005	Cosmetic compositions with long lasting skin moisturizing properties	USA, EU	Cosmetic formulation with olive oil as skin moisturizer
US11083685B2	USA	2019	Methods for treating scars and aging skin	USA	Cosmetic formulation with olive extracts for skin aging and healing
WO2001026670A1	Japan	2000	Skin-care agents, skin antiaging agents, whitening agents and external skin preparations	WW	Cosmetic formulation with olive extracts for skin aging and whitening
CN108524343B	China	2018	Composition for nourishing scalp and caring hair, and preparation method and application thereof	China	Hair care formulation with olive extracts for nourishment and growth
EP3643293A1	Spain	2018	An olive oil-based concentrate and a topically applied preparation for skin care and repair comprising said concentrate	WW	Bioactive olive-based compound that can be applied in cosmetics
CN102406581B	China	2011	Skin protecting composite with function of tightening skin	China	Cosmetic formulation with olive oil for skin aging and protection
WO2015144656A1	France	2015	Cosmetic use of an extract of olive-tree vegetable water to increase the density of hair	WW	Hair care formulation with olive extracts for hair growth
CN102716046B	China	2012	Liquid shampoo containing natural olive oil and derivative of natural olive oil and preparation method for liquid shampoo	China	Hair care formulation with olive extracts for hair repair and smoothening
US9107839B1	USA	2014	Hair care composition	USA	Hair care formulation with olive extracts for hair conditioning

Table 34: Patents applications for Olive use in cosmetics field

Patent Number	Country	Year	Patent Name	Applications	Details
WO2022218170A1	China	2022	Pineapple extract composition having anti-aging effect and preparation method and application thereof	WW	Cosmetic formulation with pineapple extracts for preventing skin aging
WO2022218169A1	China	2022	Pineapple extract liquid composition having antioxidant effect, preparation method therefor, and application thereof	WW	Cosmetic formulation with pineapple extracts as skin absorption agents
CN109846778A	China	2019	A kind of Chinese herbal medicine hair dye based on pineapple extract	China	Bio-based hair dye formulation with pineapple extract
CN112386547B	China	2019	Skin health care application of pineapple extract	China	Cosmetic formulation with pineapple extracts for skin moisturizing, aging and reducing pores
KR102238993B1	South Korea	2020	Cosmetic composition for skin barrier strengthening or moisturizing comprising fermented rice extracts, pineapple extracts and glyceryl glucoside mixture	South Korea	Cosmetic formulation with pineapple extracts for skin barrier protection and moisturizing
JP2017075118A	Japan	2015	Skin whitening agent, anti-aging agent and functional food and drink	Japan	Cosmetic formulation with pineapple extracts for skin whitening and aging
KR19990086812A	South Korea	1998	Functional cosmetics based on pineapple and coconut	South Korea	Cosmetic formulation with pineapple extracts for skin healing and aging
WO2007148951A1	Mexico	2006	Process for the production of bromelain by means of substances that induce proteins in pineapple plants	WW	Bioactive compound extraction methods from pineapple that can be used in cosmetic applications
CN105362117A	China	2015	Skin whitening and moisturizing mask and preparation method thereof	China	Cosmetic formulation with pineapple extracts for skin whitening
JP4758620B2	Japan	2004	Hair growth	Japan	Hair care formula including pineapple extracts

Table 35: Patents applications for Pineapple use in cosmetics field

Patent Number	Country	Year	Patent Name	Applications	Details
CN104922012A	China	2015	Silk cosmetic sunscreen cream	China	Cosmetic formulation including silk extract for sun protection
KR20140029674A	South Korea	2012	Cosmetic composition with silk protein hydrolysate for the acceleration of hair growth	South Korea	Cosmetic formulation including silk proteins for hair care and growth
JP2004250405A	Japan	2003	Cosmetic containing noncrystalline silk fibroin	Japan	Cosmetic formulation including silk proteins for skin moisturizing, whitening and sun proteciton
WO2022265335A1	South Korea	2022	Method for preparing low-molecular-weight silk sericin, and cosmetic composition comprising sericin prepared thereby	WW	Processing method of silk that can be applied in cosmetics
KR101340484B1	South Korea	2011	Makeup powder cosmetic prepared by using silk-gland powder of silkworm	South Korea	Cosmetic formulation with silk powder applicable in makeup products
CN107595661A	China	2017	A kind of cosmetics comprising spider silk hydrolysate and preparation method thereof	China	Processing method and cosmetic formulation of spider silk
WO2004073644A2	USA	2004	Water-soluble silk proteins in compositions for skin care, hair care or hair coloring	WW	Cosmetic formulation including silk proteins for skin and hair care
KR101340478B1	South Korea	2011	Cosmetic composition including water-soluble sericin from silk-gland powder of silkworm	South Korea	Cosmetic formulation including silk proteins for skin regeneration
WO2023282427A1	South Korea	2022	Cosmetic composition including silkworm cocoon-derived sericin and aloe barbadensis leaf extract	WW	Cosmetic formulation including silk proteins for skin moisturizing, whitening and aging
WO2020214854A1	USA	2020	Silk hair care composition	WW	Hair care formulation including silk proteins
KR20190058805A	South Korea	2017	Cosmetic Composition For Improving Wrinkles Containing Natural Extracts and Culture Media	South Korea	Cosmetic formulation including silk proteins for skin aging

Table 36: Patents applications for Silk use in cosmetics field

Patent Number	Country	Year	Patent Name	Applications	Details
WO2016159665A2	South Korea	2016	Cosmetic composition comprising slime of snail fed with berry fruits and preparation method thereof	WW	Cosmetic formulation including snail slime for skin aging
KR20160132255A	South Korea	2015	A method for mucus of Acusta despecta sieboldiana feed nautural substance and cosmetic compostion containing thereof	South Korea	Processing method and cosmetic formulation of snail slime for skin elasticity and aging
WO2014085876A1	Bulgaria	2013	Cosmetic composition	WW	Cosmetic formulation including snail slime and extract for skin aging and acne treatment
CN104586732A	China	2015	Method for extracting snail slime extract containing active enzymes	China	Processing method of snail slime to be applied in cosmetics
KR20220127097A	South Korea	2021	Cosmetic composition comprising snail slime and illite extract, and method for manufacturing the same	South Korea	Processing method and cosmetic formulation of snail slime for skin elasticity and aging
CN104688776A	China	2013	Snail slime scar repair cream	China	Cosmetic and pharmaceutical formulation including snail slime and extract for skin repair
ES2378028B1	Spain	2012	Cosmetic composition for skin rejuvenation and corresponding procedure and uses	EU	Cosmetic formulation including snail slime for skin aging
CN104323962A	China	2014	Snail slime facial mask and preparation method thereof	China	Cosmetic formulation including snail slime for skin smoothening and nourishment
CN103961300A	China	2014	Eye cream applying snail slime extract and preparation method thereof	China	Cosmetic formulation including snail slime for skin aging and smoothening
OA18050A	Cameroon	2016	Snail cream	Africa	Cosmetic formulation including snail slime for skincare
CN102793655B	China	2012	Regenerating and repairing mask liquid by applying snail mucus extract and preparation method thereof	China	Cosmetic formulation including snail slime for skin aging and repair
WO2013089449A1	South Korea	2012	Cosmetic composition containing the slime of snails fed with red ginseng and method for manufacturing same	WW	Cosmetic formulation including snail slime for skin repair and care
CN107951907B	China	2017	Method for extracting snail mucus for biological pharmacy or cosmetics	China	Processing method of snail slime to be applied in cosmetics

Table 37: Patents applications for Snail Slime use in cosmetics field

Patent Number	Country	Year	Patent Name	Applications	Details
KR101850648B1	South Korea	2017	The cosmetic compositions comprising the polysaccharide derived from the green tea enzyme extracts having a skin regeneration promoting and preparation method thereof	South Korea	Cosmetic formulation with green tea extract for skin regeneration
WO2018194360A1	South Korea	2018	Skin-improving composition	WW	Cosmetic formulation with green tea extract for skincare
CN106473987B	China	2016	The anti-ageing composition of whitening and cosmetics	China	Cosmetic formulation with green tea extract for skin whitening and aging
CN102641232B	China	2012	Rhodiola crenulata body lotion with whitening and nourishing effects	China	Cosmetic formulation with black tea extract for skin nourishment, moisturizing and whitening
CN102641228A	China	2012	Rhodiola crenulata eye cream with whitening and anti-wrinkle effects	China	Cosmetic formulation with black tea extract for skin aging and whitening
CN108852934A	China	2018	The application of the method and its compound of tea polyphenols and chlorophyll in cosmetics is extracted in a kind of green tea	China	Cosmetic formulation with green tea extract for skincare
WO2016070202A1	South Korea	2014	Cosmetic composition for improving anti-oxidation, anti-inflammation and atopic skin by using fermented black tea liquid as effective ingredient and method of preparing the same	WW	Cosmetic formulation with black tea extract for skincare
KR101474998B1	South Korea	2012	Composition comprising extracts of white tea for the care of skin wrinkle	South Korea	Cosmetic formulation with white tea extract for skin aging
KR20190094913A	South Korea	2018	Composition for preventing hair loss or reinforcing scalp comprising natural extract	South Korea	Hair care formulation with green tea extracts for hair growth
KR102305154B1	South Korea	2021	Cosmetic compositions for increasing the density and the length of eyebrows or eyelashes	South Korea	Cosmetic formulation with green tea extracts for hair growth

Table 38: Patents applications for Tea use in cosmetics field

5.2. Patents, Certifications and General Regulations in Cosmetics as a General View

5.2.1. Regulations on Human Health

Several concerns are present in consumers' minds regarding the chemical substances, heavy metals, and other synthetic ingredients cosmetics and personal care products include. Even though bio-cosmetic products are thought to be completely safe, if they are not 100% bio-originated, they still include these chemical substances and metals that can create potential risks to human health. Certifications such as COSMOS, NATRUE, ECOLABEL, and ICEA certificates ensure that cosmetic products originate from nature, are free of hazardous chemicals, and are safe for human health and the environment (Bozza et al., 2022). While there are certifications and regulations present regarding the origins of cosmetic materials, there are lack of precise regulations regarding the heavy metal levels allowed in cosmetic products. There are some limits and regulations about the heavy metal allowance in cosmetics in the USA, Canada, and China, but there are no precise limits for maximum levels of heavy metal allowance in Europe, for cosmetics. While heavy metals are stated as forbidden in cosmetic products, only Germany applies limits for heavy metals in cosmetic products, which are for lead (< 2 ppm), cadmium and mercury (< 0.1ppm), arsenic and antimony (< 0.5 ppm), however, these limits are not legally applied to other European countries (© obelis.net, 2018; Whitehouse, 2017). BIOS

is another Italian company that gives certifications for beauty products including biologic, organic, and vegan certificates, depending on the percentages of biologic and organic ingredients, processes, and type and amount of chemical substances in products (© BIOS S.R.L, 2020).

5.2.2. Regulations on Animal Safety

Concerns about animal testing have been significantly rising recently, thus increasing the importance of cruelty concerns in the cosmetic field. Many customers prefer to purchase cosmetics that have cruelty-free certifications to ensure they are following actions that are not harmful to animals' well-being. The most known certificates ensuring that products are not tested on animals are Leaping Bunny and PETA certificates, which are both used in the USA and European Countries. ICEA is the responsible organization in Italy to give cruelty-free certificates, which is connected with Cruelty-Free International and LAV (Italy) organizations and their standards (© ICEA Certifica, 2023).

5.2.3. Regulations on Environment

Various governmental and private organizations give certificates for cosmetic products, ensuring their biological and natural origins, being free of hazardous chemicals, and their low impact on the environment. COSMOS certificate ensures that products are at least 95% of natural and organic origin, which means they are also highly biodegradable and compostable. ECOLABEL is another European sustainability certificate that ensures a product's low environmental impact. These certificates also impose sustainable packaging materials and processes to the brands to decrease the carbon footprint caused by packaging (© GROUPE ECOCERT, 2023). Ingredients of a cosmetic product and their nature also affect its impact on the environment at its disposal. If a product is not 100% bio-based, it needs to be disposed of carefully and separately since some ingredients are considered toxic and harmful to the environment. Cosmetic products with chemical and synthetic ingredients should not be mixed into drains since they are not biodegradable, and due to toxicity concerns, they should be given to disposal centers or be sent to the companies or programs that are disposing or recycling used and expired cosmetics (Miranda and Madden, 2022).

5.2.4. Regulations on Anti-Counterfeiting

Counterfeiting is a serious issue in the cosmetics industry, especially for known high-end and sustainable brands, since they are less commonly found and more expensive. Therefore, there

are several regulations and anti-counterfeit methods to protect the rights of brand owners. Many brands are using digital systems such as QR Codes and RFID to prove the authenticity of their products and ensure their customers (Meng et al., 2023; Ma et al., 2015). In addition to this technology, there is also a Chinese patent available in the literature that uses tokens to prove the authenticity of cosmetic products from their packages (Jia, 2011). EU Commission has several regulations to prevent counterfeiting in cosmetics which mostly work by notifying original brand authorities and customs authorities (© Cosmetics Europe, 2023). Since bio-based cosmetic products are increasingly preferred, scarcely found in markets, and have higher prices compared to conventional cosmetic products, they are in a risky position for counterfeiting, and thus regulations should be set for these types of products.

6. CASE STUDIES OF COMPANIES SPECIALIZED IN BIOMATERIAL USE

With increasing concerns towards health and sustainability, the demand for biomaterials in the cosmetics and personal care industry is rising, which is leading to an increase in sustainable production, new start-ups specialized in biomaterials and sustainable cosmetics or upcycling actions towards wasted biological materials. In this section, some examples from the sustainable cosmetic market are examined by disclosing their products, sustainable actions, methods, and biomaterials evolutions in these sustainable products. Companies examined in this section have been chosen to be representative of the biomaterials mentioned in this research. Searching of these exemplary companies has been conducted with keywords including ‘’biocosmetic brands’’, ‘’cosmetic brands with bio-based materials’’, ‘’natural cosmetics’’ and other content including sustainable and biomaterial-related keywords.

6.1. Kaffe Bueno

Kaffe Bueno is a Danish company that utilizes coffee byproducts such as coffee grounds by upcycling and transforming them to obtain personal care and cosmetic material. Coffee has several benefits to skin health and capturing these benefits is one of the purposes the company pursues. In Kaffe Bueno’s business model, coffee grounds are the main element. Spent coffee grounds from restaurants, cafes, or hotels are collected and sent to Kaffe Bueno by partner logistic companies. Then, the company transforms these coffee grounds, upcycles them, and produces biomaterials that can be used in cosmetics, personal care, or food supplements. The company desires to recycle coffee because it is a plant that is consumed very widely, and when it is wasted, it dissolves in landfills, releases methane, and damages the environment significantly. With the upcycling of coffee grounds that are wasted after beverage production, a large amount of possible waste from the environment will be eliminated and coffee, a plant with various health benefits will be valorized by being a natural ingredient in personal care products (© Kaffe Bueno ApS., 2023).

Kaffe Bueno formulizes coffee-based materials for personal care, nutraceuticals, and food and beverage industries. The company produces and sells two main products to companies that desire to add coffee-based materials to their formulations. These two materials are named Kaffoil and Kaffibre™. Kaffoil is a type of coffee oil that provides several benefits in the context of skincare such as sun protection, anti-cellulite, skin repair, moisturizing, and maintaining hair health. Kaffoil is applicable for scrubs, face and body oils or serums, lip balms, shower gels, shampoos, sunscreens, and lip balms. Kaffibre™ is a proprietary cosmetic raw

material that is produced by Kaffee Bueno by upcycling coffee grounds. Kaffibre™ a material that is in the particle form and most appropriate for use in peeling and exfoliating scrubs, masks, cleansing gels, and lip balms. The benefits Kaffibre™ provides when added to cosmetic products in moisturizing the skin and preventing cellulite (© Kaffe Bueno ApS., 2023).

Kaffe Bueno is one of the startup companies that is a member of B Corporation, which means the company meets the standards of being significantly impactful in terms of environmental and social sustainability. One of the aims of the company joined B Corporation is to also support the coffee farmers in Colombia, addressing their problems and increasing their welfare. Kaffe Bueno is one of the few companies in Denmark to become a member of B Corporation and effectively address the social and environmental impact of the beauty industry and develop effective solutions to handle coffee waste while protecting its benefits to health (© Kaffe Bueno ApS., 2023).

6.2. 100% PURE

100% PURE™ is a US-based company that provides cosmetics and personal care products that are produced by using sustainable plant-based biomaterials and environmentally-conscious production processes. The most important mission of the company is to provide natural, biodegradable, pure, healthy, and cruelty-free products to the people while protecting the environment and improving the well-being of people and animals by practicing sustainable actions. The main ingredients the company uses in its products are fruits, vegetables, tea, and cocoa, and their products are completely free from colorants, and heavy metals. They also have certifications proving that their products are free from toxic chemicals (100% PURE™, 2023).

100% PURE has three main ranges of products which are make-up, skincare, and hair and body products which are based on biomaterials. Their make-up products are also called Fruit Pigmented® Make-up since all products include several fruit extracts that are beneficial for the skin in many different ways. Make-up products include fruits such as passion fruit, peach, plum, berries, tomato, apricot, olive, avocado and many more. Along with all these fruits, make-up products also include other biomaterials such as grains like rice or wheat, honey, flower extracts such as chamomile, aloe vera, coffee, different kinds of tea extracts, cinnamon, leaf extracts, mineral powders, and vitamins. The company sells a very wide range of nature-based make-up products including lipsticks, bronzers, foundations, mascaras, blushes, eyeliners, eye palettes, primers, and balms (100% PURE™, 2023).

Another group of products 100% PURE is the skin care group which includes daily or occasionally used personal care products that are formulated with nature-based materials. The products belonging to the skin care group consist of cleaners, toners, face oils and serums, moisturizers, sunscreens, face scrubs and masks, and eye creams. These products are also classified according to the skin conditions they are formulized for such as acne healing, anti-aging, brightening, or daily uses according to the skin types such as dry, oily, combination, and sensitive skin. All these skin care products are formulized including different types of plant-based biomaterials such as all the fruits mentioned above, tea, coffee, flower extracts, grains, and their forms such as oils or powders (100% PURE™, 2023).

Finally, the company provides hair and body care products that are rich in bio-based materials to consumers who are conscious about their choices in terms of health and environment. The hair care products the company provides range from shampoos to conditioners and treatment products such as hair serums and oils. Body care products include hand creams and sanitizers, body washes, scrubs, sunscreens, treatment products, creams, and oils. All these products include the biomaterials mentioned above in the section on makeup and skin care products (100% PURE™, 2023).

Along with the use of clean and biological raw materials in product formulations, 100% PURE Company also follows other sustainable practices to strengthen their positive impacts on the environment and society. The company uses recycled materials for its packaging and it aims to end petroleum-based packaging materials completely. Additionally, they also provide free products or samples to the consumers who recycle their products in their stores. Moreover, they practice sustainable shipping by using boxes made from peanut wastes and corn starches instead of less biodegradable synthetic materials. The company also supports the well-being of underprivileged people, local farmers, children, and animals by being partners and funding social projects and actions in Africa or other rural regions (100% PURE™, 2023).

6.3. AlgAllure

AlgAllure® Skin Care is an American specialized sustainable beauty brand that provides skin care products that are based on marine algae extracts. The brand mainly originated from its parent biotechnology company AlgEternal Technologies™, which processes and formulates products from algae. AlgEternal Technologies™ aims to decrease carbon footprints from fossil and synthetic materials, create more sustainable products, and increase the quality of life. The parent company also uses superior technologies in algae harvesting processes to make each step

of their product formulations sustainable and chemical-free. Thanks to the technologies and methods they use, water use, land occupation, and carbon emissions are minimized while they are obtaining very high-quality biological materials from algae. Their cosmetic brand AlgAllure is one of the main two brands of the parent company along with ElixEarth, the brand name of algae-based soil amendment for improving soil quality (AlgAllure®, 2023).

Red marine microalgae are the main raw biomaterial of AlgAllure® skin care products. The brand name of the main ingredient that is composed of red marine algae, produced and used by AlgAllure's skin care products is PhycoDerm®. This type of algae is being used in skin care products due to its significant benefits such as anti-aging, protection from UV lights, skin rejuvenation, and nourishment. Collection, growing, harvesting of algae, and formulation of products are done by the scientists of the parent company. The brand provides mainly anti-aging skin care products with the name 'age-defying'. The type of products they have in the brand's portfolio can be listed as night creams, daytime moisturizers, serums, and cleansers. All these personal care products of AlgAllure are free of parabens and sulfate, along with being vegan, hypoallergenic, and cruelty-free. Due to the use of high technologies and sustainable biomaterials, products are slightly expensive, which makes AlgAllure a high-end beauty brand. The company also has required health and sustainability certifications on their products. Additionally, they also hold patents on their formulations and processing technologies (AlgAllure®, 2023).

6.4. BYBI

BYBI is a UK-based natural beauty brand that produces sustainable beauty products with plant-based natural materials and uses processes that are less impactful in terms of carbon footprint. The main purpose of BYBI is to produce products that will positively affect the environment instead of negatively. They formulate their beauty products intending to neutralize their carbon footprint. The founders, who are also the ones formulating the products have managed to produce a skincare product, which is a brightening facial oil, that is carbon-negative, due to the use of upcycled and recycled materials and conscious production methods and packaging procedures. Moreover, this product named Glowcurrant Booster, is known to be the first carbon-negative beauty product that has been produced in the world (BYBI, 2023).

Products of the BYBI brand mainly consist of superfoods, fruits, vegetables, and other vegan ingredients, which also makes products cruelty-free. They mostly used upcycled materials such as fruits that they obtained from other supply chains. Along with the fruits that are present in

almost all products, plant-based oils such as coconut, shea, cacao camellia, and other seed oils are widely used in products for their benefits and as substitutes for several chemicals. The company serves several skin care products which can be listed as day and night face oils, sunscreens, moisturizers, face cleansers, masks, creams, eye creams, lip balms, tonics, face and body sprays, and serums that are all cruelty-free and nature-based (BYBI, 2023).

In addition to the clean biomaterials they use inside products, BYBI also follows other sustainable procedures to decrease their carbon footprint overall. First of all, their manufacturing and harvesting machinery and tools are the ones that use the least energy possible. Moreover, many of their manufacturing tools are also manual, which requires zero energy or water use. For shipping, the company uses transportation modes that require less gas use and less travel time, which include water transportation. Furthermore, recycled glass only with biodegradable inks is the main packaging material preferred for products instead of harmful and less biodegradable materials such as plastics or aluminum (BYBI, 2023).

6.5. Kadalys

Kadalys is a French-Martinique small beauty brand that specializes in banana-based cosmetics and personal care products. The founder of the company formulated banana-based products to obtain and evaluate the wastes of bananas, which are significant in amount, such as tree woods, peels, leaves, roots, green bananas, flowers, and unconsumed fruits. The purpose of the founder is to produce beauty products that lack hazardous chemicals to the skin and act responsibly towards nature by controlling wastes and energy, water, and other sources of consumption. Kadalys products are certified by COSMOS which proves they add organically grown materials in significant amounts, ingredients are almost completely biodegradable, levels of preservatives are minimal, and they respect human health, society, and the environment. Sustainability is the core of the company and it is targeted to produce formulations that are 100% nature-based. They also retrieve bananas from Martinique and Guadeloupe and support local farmers in these countries (Kadalys, 2023).

All of the products Kadalys serves are vegan, cruelty-free, and formulated mostly from ecologic bio-based materials and their bio-active compounds. The company even possesses patents for several banana-based bio-active compounds and cosmetic formulations of banana actives with the combination of other bio-actives of different materials such as seed oils. The brand is mainly known as a banana brand, and bananas and their byproducts are the most common ingredients present in their product formulations. However, along with different types of upcycled bananas

such as yellow, green, or pink, other biomaterials are also used in Kadalys' beauty products. Aloe vera, ginger, argon, wheat, citrus, castor, tea, jojoba, blueberry, shea, macadamia, various flowers or tropical fruits and their acids, sugar cane, corn, and even other biological microorganisms such as algae are some of the low impact biomaterials that are present in Kadalys products (Kadalys, 2023).

Kadalys markets a wide variety of personal care and cosmetic products that are formulated for different skin conditions. The main product types the company has can be listed as cleansers, tonics, exfoliants, creams, moisturizers, face oils and serums, eye and lip care products such as masks and balms. These products are also grouped depending on the skin types and aims of the products such as dry and dull skin, anti-aging, sensitive and red skin, or make-up removal and cleansing products (Kadalys, 2023).

In addition to the biologic and biodegradable biomaterials Kadalys applies to its products, it also follows sustainable actions to decrease its footprints on operations such as packaging. The packaging company uses, including kit and tote bags, labels, or tags, is from completely biodegradable and recyclable materials such as cotton, paper, and cardboard. And their packaging materials are also completely free of chemical substances such as dyes. It is seen that Kadalys is a unique brand in the sustainable beauty market, thanks to its exclusive green formulations, sustainable actions, clean biomaterials they use, and its support to society (Kadalys, 2023).

6.6. LOLI Beauty

LOLI Beauty is a US-based sustainable cosmetics and personal care brand that serves products natural, hand-selected, and responsibly sourced food-based biomaterials, to customers who are conscious in terms of health and environment. The name LOLI refers to 'Living Organic Loving Ingredients'. The products the company provides are vegan, natural, obtained from local farming, cruelty-free, ecosystem-friendly, and free of hazardous chemicals. In addition to these, the biomaterials they apply to their products consist of only raw foods or upcycled food wastes. Products of LOLI are also certified by MADE SAFE®, which proves that the ingredients they use in products are safe for human health and other natural ecosystems. Products with MADE SAFE® certification means they are made with ingredients that are free of toxic chemicals, heavy metals, pesticides, biological system disruptors, carcinogens, and other toxins that may be allergic. This certificate also proves that products are safe for other natural ecosystems such as earth and water (LOLI Beauty, 2023).

LOLI brand provides various kinds of products that are formulized for skin, body, and hair care. The main divisions of their products consist of face and body oils, lotions, and tonic waters. While there are few number of product forms, these three forms of products are used for many different purposes such as face and body scrubs, serums and oils, lip balms, moisturizers, cleansers, toners, and prevention of hair damage or softening. These products contain various beneficial food-based biomaterials which are different types of fruits, plants, grains, flowers, or other plants. Most common bio-based ingredients in the products can be exemplified as grape, date, carrot, apricot, matcha, plum, different types of tea, chamomile, flaxseed, citrus fruits, blueberry, cornflower, coconut, pomegranate, lavender, chia, and many more food-based biomaterials (LOLI Beauty, 2023).

Along with providing safe and bio-based ingredients in formulations, LOLI Beauty also implements sustainable practices in their packaging and shipment processes. All beauty products are served in glass jars which are refillable and reusable in many different ways such as a storage bin. Moreover, as for shipping processes, they only use compostable materials in their bags, boxes, and labels that include shipping information. The company also donates regularly to organizations that are empowering society and life conditions (LOLI Beauty, 2023).

6.7. Nature in Bottle

Nature in Bottle is an American wholesaler brand that provides a wide variety of natural raw biomaterials for cosmetic and personal care companies to be used in products. Mostly in the form of oil, all the products that the company provides have organic, cruelty-free, ISO, kosher, and many more trusting certificates proving the safety of the materials. The company follows its own P.U.U.R.E. promise, which carries the meaning of pure and authentic products they serve. The biological oils they produce and sell are free of all kinds of synthetics and contaminants, and all production steps are carried out by obeying ethical standards and clean production principles (Nature in Bottle, 2023).

Nature in Bottle is an important player in the cosmetics material market since while it ensures the high quality of the products, it also sells these products at a competitive price that strengthens its position in the market. Along with providing biomaterials for cosmetic producers and following green practices, the company also supports local small-scale farmers, develops projects for improving conditions in local hospitals, water systems, and schools, and creates more jobs in underprivileged communities. In addition to these, the company also works on

developing 100% recycled packaging for its products to decrease its carbon footprint (Nature in Bottle, 2023).

In the product portfolio of the company, it can be seen that they serve mainly 8 different groups of products, which are essential oils, carrier oils (mostly consists of fruit and fruit seed oils), absolutes (mostly consist of flowers, used for aromatherapy and skincare), ayurvedic herbal oils (therapeutic oils), infused & macerated oils (herbs and flowers, formulized for cosmetics products and skin nourishment), hydrosols & floral waters (formulated for perfumes, fresheners, mists and sprays), natural fragrance oils (for bath and body products, or home applications) and chakra blends (mixtures of different materials targeted for wellbeing of mind and body). In all these 8 groups, hundreds of different types of plants including fruits, vegetables, grains, flowers, tea, and spices are present in the forms of oil, water, and extract, formulated for many different skin types and conditions. These biomaterials are generally sold in bulk to cosmetics and personal care producers who would like to add these materials as sustainable and healthy substitutes for chemical ingredients (Nature in Bottle, 2023).

6.8. Primex

Primex is a marine biotechnology startup company that is based in Iceland. The company is one of the significant chitosan and chitosan-based producers in the Iceland market, and also one of the leaders of high-quality chitosan producers worldwide. Along with producing high-quality raw material chitosan, the company is also known for its sustainable and environmentally friendly production methods. Chitosan products are mainly obtained by processing the shells of crustaceans, and one of the primary sources of the company is wild shrimp shells. There are four main groups of chitosan-based products in the company's portfolio which are under the brand names ChitoCare®, ChitoClear® and LipoSan Ultra®, and SeaKlear®. These different kinds of products are mostly in the form of chitosan powder, and the active ingredients in them are suitable for application in different industries such as food supplements, agriculture, biomedical, and cosmetics. All these products have certifications of being pure and natural (Primex, 2023).

ChitoCare® and ChitoClear® are two of the product groups of the company which is used for cosmetic applications. ChitoCare® is a brand which founded by a company primarily focusing on beauty and medical care. ChitoCare® Beauty is one of the lines of the ChitoCare® brand which includes body lotions, scrubs, anti-aging serums, shower gels, and face creams, which are rich in chitosan biomaterial. These products are effective in skin repairing, firming,

moisturizing, anti-aging, UV protection, and maintaining the skin barrier. In addition to these topical application products, ChitoCare® Beauty also provides multivitamins that are effective in maintaining and improving skin, hair, and nail health. Along with the beauty line, ChitoCare® also has a group of medical care products such as healing gels and sprays, under the brand name of ChitoCare® Medical which targets wound healing and preventing skin irritations, infections, and other imperfections (Primex, 2023).

ChitoClear® is the brand of the product which is the pure chitosan powder that can be used as a raw biomaterial in cosmetic formulations. ChitoClear® products are highly biodegradable and biocompatible, which increases the level of sustainability of applied products. Being colorless, odorless, natural, and non-toxic, ChitoClear® is very appropriate for cosmetic and personal care uses. As for skin care, ChitoClear® is beneficial for skin moisturizing, and relieving itching, sunburns, and irritations. For hair care, chitosan products are effective in making hair softer thus making it easier to comb, repairing hair damage and renewing the hair tissue, protecting hair against heat treatment and harmful sun lights. ChitoClear® chitosan powder is also applied to other cosmetic product groups such as soaps, make-up products such as shadows and lipsticks, aftershave products, and bathing agents (Primex, 2023).

In summary, Primex provides high-quality raw biomaterial of chitosan that is produced with sustainable practices and certifications, to several cosmetics and personal care brands. Along with the cosmetics sector, Primex provides their products to other industries such as agriculture, medicine, and food to obtain many benefits of chitosan which vary from weight management, water purification, or increasing the growth rate of crops. Primex is known for its innovations and practices towards sustainability and acts as a pioneer for science and technology startups with creative ideas. The company also holds an innovation award from Iceland that proves its success in the research and development area (Primex, 2023).

6.9. Provital

Provital is a Spanish company that produces natural ingredients and development of formulations for cosmetic products. Their material portfolio includes fresh fruits (raspberry, orange, olive, watermelon, saw palmetto), dried fruits (almonds, pistachio, macadamia), seeds (soy, argan, coffee, sesame, jojoba), seaweeds, trees (acacia, shea, eucalyptus), flowers, roots (turmeric, ginger, licorice), spices (cinnamon, pepper, clove), cereals (oat, barley, rice, wheat), or other plants (tea, thyme, henna, vine), and formulates these biomaterials to obtain more sustainable, healthy and affordable beauty products. The company uses the ‘Do Care’ statement

to point out its sustainability purposes including the wellbeing of nature and people's lives. The main purpose of the company is to produce high-quality cosmetic ingredients that are completely nature-based, respect the environment, and decrease footprint while formulating and producing these biomaterials (Provital, 2023).

Provital Company provides several plant-based materials for cosmetic use and they have two main types of product groups which are named CareActives™ and CareMotives™. CareActives™ is the product group that serves cosmetic formulations to balance and maintain skin health and act as decent and daily 'care' products. There are ten different types of products present in the CareActives™ group which mostly include hair and scalp care products, giving benefits such as balancing hair sebum, stimulating hair growth, and increasing hair mobility. Other than hair care products, CareActives™ also has product formulations that are anti-aging, moisturizing, and for fighting skin stress, irritations, and imperfections (Provital, 2023).

CareMotives™ product group includes five different types of products and they can be listed as OilyCares, ImagineCares, VitaCares, SparkCares, and EcoCares. While CareActives™ products are more about active ingredients and formulations, CareMotives™ is a brand that consists of different forms of natural materials and focuses more on authenticity and emotions. OilyCares™ include many different types of plant-based oils such as carrot, aloe vera, amber, avocado, and arnica, which have various benefits to the skin, such as anti-cellulite, anti-aging, moisturizing, anti-irritation, purifying, anti-stress, sun protectant and more, depending and differing by the plant. ImagineCares™ includes a wide range of fruit, wheat, plant milk, kinds of vinegar, rain, hydrolyzed plants, and mineral extracts serving various skin conditions. A variety of natural formulations are used to treat aging symptoms, moisturize skin, sun protection, hair, purify, and exfoliate the skin, and act as an antiseptic, depending on the material and product type. VitaCares™ group mostly consists of extracts of flowers such as honey, acacia, aloe vera, or other plants such as cucumber, coconut, or pomegranate and gels produced by these extracts. Products of these groups include most traditional formulas of beauty and health maintenance which is used and trusted by society as a whole. SparkCares™ is a group of products that contains several combinations of natural materials in different forms to obtain the most effective and multi-functional formulations. Products in this group generally named polyplant products, which are formulated for various conditions such as hair loss, skin stress, anti-aging, metabolism booster, energizing, blood flow activator, and many more. Combinations of product formulations mostly include different groups of plants such as algae, herbs, and fruits. The final group, EcoCares™ includes products that are certified by COSMOS,

and have been proven to be organic, respectful to nature in the contexts of materials and production processes, paraben-free, and authentic. Products belonging to this group can be listed as acai, honey, aloe vera, argan, chamomile, coffee, and cocoa (Provital, 2023).

Provital is one of the sustainable ingredient companies that provides a very wide range of biomaterials and formulations including different combinations of biomaterials for cosmetic use. Along with providing these materials, the company also follows environmentally conscious production methods and packaging practices to catch up on their aims to protect the well-being of nature and society. The company also became a partner and has implemented several projects about sustainable actions, solidarity, renewable energy, and diversity to support the world and society in a more impactful way (Provital, 2023).

6.10. UpCircle Beauty

UpCircle Beauty is a UK-based sustainable skincare brand that produces various beauty products with biological and upcycled ingredients such as fruits, coffee, and other types of food. The company was founded by two entrepreneurs who used coffee as a skincare ingredient in their experimented products and launched their ideas at a coffee festival. After that point, they included many other food-based biomaterials in their portfolio and kept formulating new skincare and haircare products. The company serves many different categories of care products which are natural, cruelty-free, vegan, and certified from B Corporation. They have a large portfolio of upcycled materials which consist mostly of fruits and other plant elements, and they use these biomaterials in the forms of fruit waters, extracts, powder, and oil. The main upcycled biomaterials applied by the company to the products are listed as bergamot juice, blueberry extract, coffee grounds, oat powder, argan shells, chai spices, olive stones, date seeds, coffee oil, kiwi juice, maple bark, hemp seed oil, apricot stones, chamomile stems, rose petals, raspberry seeds, pink berries, and several other fruit waters (UpCircle Beauty, 2023).

UpCircle Beauty Company divides its products into categories depending on the skin types or product types. As for skin types, they formulate and serve products varying depending on the skin condition of the customer. They group products according to their benefits to different types of skin conditions such as dry, dull, acne-prone, mature, and sensitive skin. For product groups, they serve face serums, eye creams, anti-aging care products, face masks and toners, exfoliators, cleansers, sunscreens, moisturizers, hand and body lotions, scrubs, washes, and soap bars. In addition to these skincare products, they also sell a shampoo cream with pinkberry as a hair care product. Along with all these care products, they also sell several body accessories

such as candles, face massage tools, razors, cotton buds, and face cloths (UpCircle Beauty, 2023).

In addition to natural biomaterials the company uses in its products, it also encourages its reuse and refill scheme to its customers so they can decrease the use of packaging material and their carbon footprint. With this action, they also transform their production and shipment processes more sustainably. Their refill scheme works as collecting empty bottles and other packages from customers by cargo, filling bottles again, and sending them back to users. Customers use this service frequently because they are not the ones who are responsible for shipping fees and in the end, they obtain the same amount of the product by a 20% discount. The company includes a refill scheme for the products' face scrubs, masks, toners, serums, oils, moisturizers, shampoos, sunscreens, body washes, and lotions (UpCircle Beauty, 2023).

6.11. The Upcycled Beauty Company

The Upcycled Beauty Company is a startup company that aims to decrease the footprint of cosmetic products to the environment completely in the future. The vision of the company is to reach a market with beauty products that are completely made from upcycled materials. With the support of upcycled beauty and zero waste movements, the quality and efficacy of wasted food are transformed into valuable skin care biomaterials. The company has practices over cosmetic products in many perspectives, such as replacing materials, supporting refillable packaging systems, replacing plastic materials with more sustainable packaging materials, and valorizing food waste. While formulating, producing, and packaging products, the main target of the company is to use only upcycled materials, for both raw ingredients and packaging (The Upcycled Beauty Company, 2023).

In its portfolio, the company has three different types of products which is formulated for cosmetic use. These three types of cosmetic material are named NECTA®, CRUSH, and TONIQ. All these groups of materials are produced by upcycling food-based materials such as fruits and grains. NECTA® group of products are cosmetic materials that are in the form of luxurious oil. There are three types of NECTA products in the portfolio which are Raspberry NECTA, Blueberry NECTA, and Hemp NECTA. While Raspberry and Hemp NECTA are mainly for skin protection, hydration, and soothing, Blueberry NECTA is additionally protective against light exposure. All these products are formulated by upcycled food sources appropriate for skincare products, and supported by safety certifications. CRUSH™ is a group of products that are in the form of powder, mostly produced by transforming leftover seeds of

fruits, which is suitable for applications in face and body scrubs or exfoliators in general. There are five different types of CRUSH™ products in the company's portfolio which are Olive, Rice, Charcoal, Blueberry, and Raspberry CRUSH. Different grades of products are provided depending on the type of product to which CRUSH materials are applied. CRUSH™ products apply to almost every type of beauty product including skin, hair care, and makeup products. Finally, TONIQ® is the group of materials that are soluble in water. TONIQ® products are made from upcycled food and drink wastes, which are mostly grain-based. There are three types of different TONIQ® products that are Faba TONIQ®, Barley TONIQ®, and Gin TONIQ®. Faba TONIQ® is made from hummus production wastes and can be used as a material in hair care products. On the other hand, Gin TONIQ® is made from fermented vegetal glycerin, and Barley TONIQ® is made from upcycled barley. These two formulations are good for moisture protection and skin smoothening (The Upcycled Beauty Company, 2023).

Other than formulating and providing cosmetic materials from upcycled food waste, The Upcycled Beauty Company also provides and supports several sustainable packaging ideas. First of all, they propose packaging made of bio-based sustainable materials such as mycelium and other food waste, which are more compostable and biodegradable. Secondly, they encourage recycling and reusing packaging materials that have infinite lifecycles such as aluminum. In addition to these, refilling systems are another opportunity that significantly decreases the packaging material use, especially plastics. With refillable containers that are purchased only once, greenhouse gas emissions can remarkably be decreased. Finally, dissolvable and naked packaging materials aim to leave no waste after use. These methods are most appropriate with soaps, that packaging materials will disappear after the touch with water since they do not contain micro-plastics (The Upcycled Beauty Company, 2023).

7. SUSTAINABLE PACKAGING IN COSMETICS INDUSTRY

While the ingredients of cosmetics and personal care products are vitally important and concerning customers, the outer packaging of these products is also important regarding sustainability. Therefore, packaging materials, the way they are used, disposed and recycled is crucial since it affects the overall impact and sustainability of cosmetics and personal care products. Plastics have been used as primary packaging material for cosmetic products for decades, but since concerns towards plastics, the amount of plastic waste in the environment caused by product packaging, and their damage to human health, nature, and other living creatures have shifted consumer needs and expectations toward more environmentally friendly options (Cinelli et al., 2019). Recently, there are several sustainable packaging materials are present in products such as paper, glass, wood, or some biomaterials obtained from biological creatures or waste (Bom et al., 2020).

Also, there is a rising trend over bioplastics in the packaging industry, which are used as more recyclable, compostable, and biodegradable options for cosmetic packaging, to decrease the overall carbon footprint. Bioplastics can be produced by many different types of bio-based materials such as plants, fruits, animals, and other organisms (Ibrahim et al., 2021). Several biomaterials that are also mentioned in this research such as algae, silk, chitin, fungi, eucalyptus, and byproducts or wastes of fruits such as banana, pineapple, citrus fruits, and coffee are used to produce biodegradable bioplastics and other sustainable packaging materials, especially in cosmetics sector (Ibrahim et al., 2021; Karne et al., 2023; Yaradoddi et al., 2022; Long, 2022). So, these biomaterials are not only important as a part of the product but also its sustainable packaging.

Packaging in cosmetic and personal care products is significantly important, due to the requirements of products to be separated from packaging and prevention of any reactions or leakage from the package. Therefore, glass is a highly preferred packaging material in cosmetics due to being impermeable and ensuring the sterilization of the cosmetic product, in contrast to plastics that have the possibility of toxicity of the products caused by microplastic leakage. Additionally, glass packaging is highly suitable for refill and reuse, which is another common sustainable method of packaging that is increasingly being used by many beauty brands. Glass is almost 100% recyclable and therefore preferred by consumers who have environmental and health concerns (Glass Packaging Institute, 2016). Glass packages are also perceived as high quality, elegant and luxurious, hence they are more preferred by high-end brands and customers. Even though glass packaging has serious advantages such as being non-

toxic, resistant, recyclable, high quality, and perceived as premium, it is fragile and not durable by nature and heavier than its substitutes such as plastics and paper, additionally, recycling of glass bottles can be costly and cause carbon emission due to the processes such as melting (Srivastava et al., 2022; Shivsharan, Raut and Shaikh, 2014).

Metal packaging is another type of packaging that is considered more sustainable compared to plastic packaging. The most commonly used metals in cosmetic packaging are aluminum, lead, and steel which are formed into bottles and dispensers and provide ease of use (Shivsharan, Raut, and Shaikh, 2014). Metals can be preferred as packaging materials since they are more durable, resistant, and lightweight compared to glass, and cheaper to recycle (Srivastava et al., 2022). Metal bottles are also the most common tools for reuse and refill systems in the cosmetics and personal care industry. Plus, metal packaging is also considered high-end and luxurious by some customer groups and therefore preferred to other packaging materials (Nobile, 2017). The most significant drawback of metal packaging is that it may not be suitable for some cosmetic products since it is reactive by nature and may give reactions to products and cause contamination (Sun, 2020).

Paper is another type of bio-based sustainable packaging material that is mainly used in outer parts of the product such as boxes or tags. It is not used as commonly as other materials such as plastics, metals, and glass due to most of the cosmetic products' liquid form, and the low barrier properties of the paper (Kunam et al., 2022). However, it is commonly used in solid products such as soaps or solid shampoos and other skin care products (Resimović, Kovačević and Brozović, 2022). Paper is the material that has the highest recycling rate among all packaging materials which is more than 80% (© Two Sides, 2022). Therefore, paper is a preferred material for many beauty brands as outer packaging or shipping material.

Materials used to make paper also affect its level of biodegradability and recyclability. Recently, plants such as hemp have been used to produce paper which is used for packaging, so hemp is considered as a packaging biomaterial which highly biodegradable. Hemp is preferred as a packaging material because it is highly durable, recyclable, requires little amount of water and time to grow, does not require any chemical processing, and its high barrier properties (Promhuad et al., 2022; KMFinfotech, 2023). Moreover, hemp is also suitable for bioplastic production that can be used in the packaging of many different types of products including cosmetics and personal care. Hemp is considered a carbon-negative crop that absorbs carbon dioxide gases and helps soil quality maintenance. Therefore, hemp-based bioplastics are eco-friendly, low-cost, durable, anti-allergic, compostable, and biodegradable packaging

materials that can be used for cosmetic products such as bioplastic jars and bottles (The Hemp Plastic Company, 2023).

Bamboo and wood are some of the other sustainable bio-based materials that are used for cosmetic and personal care product packaging. These biomaterials mostly take place on the outer packaging of products such as boxes, tags, or lids as a substitute for less biodegradable products like plastics (Resimović, Kovačević and Brozović, 2022).

In short, there are several sustainable material options for cosmetics and personal care product packaging including glass, paper, metals, and the mentioned biomaterials themselves such as plants, animals, microorganisms, or food wastes. Depending on the product form and chemical composition of the product, place of the packaging (inner or outer package), expected qualifications of the product such as eco-friendliness, durability, price or impermeability, and type of materials to be used in products should be determined to reach maximum efficiency and safety in general.

8. CONCLUSION

Biomaterials are gaining importance for different industries at an increasing rate, which is the consequence of many factors including environmental, social, and health concerns of the society. The cosmetics and personal care industry is one of these industries where biomaterial use is highly preferred and desired, due to the higher sustainability properties of bio-based materials and their innocent nature which is free of hazardous and synthetic substances. There is plenty of research present in the literature about biomaterials in cosmetic applications, however, the topic is still relatively new, which also means there is place for further research and improvement. Particularly, there is a lack of a study where different aspects of biomaterials are integrated into one research. This thesis aimed to cover various perspectives of biomaterials in the cosmetic context, including their application on products, processing technologies, advantages and disadvantages, real examples from the market, development status, patents and certifications granted, and their comparative review in terms of environmental impact.

A comprehensive literature review has been performed to analyze different and distinctive aspects of biomaterials in cosmetics. 4 research questions have been formed to realize the use of biomaterials, their development status, implications of their use, and real-life examples. 19 biomaterials have been selected as representatives to be discussed in this thesis, after the initial comprehensive research about biomaterials in general. Then, separate and consecutive research was conducted in the Google Scholar database for each material, to form a detailed analysis of biomaterials in the cosmetic field. In the first section of research findings, all retrieved information from sources have been listed, grouped, and analyzed depending on the search perspective, and different sections have been formed for each biomaterial. Non-scientific extensions have been added to the end of each section to show real examples from the market to support academic research findings.

Detailed analysis of biomaterials shows that they can be used to heal various skin conditions and can be substituted with conventionally used chemical substances. On the other hand, biomaterials are highly biodegradable, compostable, and biocompatible, which supports the fact that their use is appropriate in cosmetics. Biomaterials can be applied to a wide range of products including make-up, showers, skincare, nail care, and body care products. While biomaterials are considered sustainable, healthy, and trusted by society, they may have some disadvantages such as costly and unsustainable processing methods, negative and doubtful perception of consumers for newly used biomaterials, and relatively higher carbon or water footprint. Numerous known cosmetic brands use biomaterials in their products increasingly, in

addition to the many smaller-scale sustainable beauty brands that focus their business models on bio-based and sustainable cosmetics.

Secondly, the development status of each material has been examined to see how effective they are in terms of cosmetic applications and sustainability. Specific LCA criteria have been defined such as recyclability, renewability, biodegradability, biocompatibility, and others, to evaluate the sustainability level of materials, and water and carbon footprints have been used for comparing materials with each other in the context of environmental impact. Other than LCA criteria, aesthetic characteristics and origin-related information about biomaterials have also been added to summary tables that include every property related to the development status of a specific biomaterial. These tables can also be used to obtain information about the names of several suppliers, other industries in a biomaterial that can be applied other than cosmetics, forms of the material used in cosmetics, and possible processing methods. Comparative analysis with footprints showed that plant-based materials, especially fruits, generally produce relatively lower carbon emissions and require less water in their production phases till they become cosmetic materials. However, coffee and tea, which are also plant-based materials, show the highest numbers in their group, which makes them less sustainable in terms of carbon and water footprints. Chitin turns out to be the most impactful material of all both in terms of carbon and water footprint. On the other hand, there is a lack of data regarding the carbon and water footprint values of some biomaterials, and therefore analysis conducted without these values is limited and results may not be considered completely precise.

Patents and certifications retrieved from the Google Patents database support the literature findings and have been used as real applications of biomaterials. In the past, many patents have been granted to several innovators for their studies on cosmetic formulations of biomaterials or different processing methods of biomaterials to be used in the cosmetics field. Most of the 219 patents retrieved are about different cosmetic formulations for products and belong to Asian countries such as South Korea and China, which may be evidence of the level of research and development of the beauty industry in Asia. It is also seen that the number of patents is in an increasing trend in the most recent year range of 2015-2022, which may also be considered as proof that research and application of biomaterials in the cosmetic industry is rising. General regulations on cosmetics and personal care products are also important for bio-based cosmetics since these products need to obey several rules regarding sustainability, animal safety, biologic and non-biologic ingredients, anti-counterfeiting, and disposal. Different internationally

accepted certifications are applied to ensure the trustworthiness of bio-based products including COSMOS, NATRUE, ECOLABEL, and ICEA.

Case study analysis including exemplary companies showed that there are sustainable startups and small-scale beauty brands that are focusing on using biomaterials in their cosmetic and personal care products to provide both sustainable and healthy options for concerned customers. Moreover, several companies are doing upcycling for food waste to produce valuable biologic raw materials to be used in cosmetic formulations, as a remedy for skin imperfections and nutrition. These case studies have been presented in this thesis as supportive materials for the academic resource review and show the real industry application of biomaterial use over the examples of companies that specialize in biomaterial-based cosmetics and personal care products.

While this thesis mainly focuses on the biomaterial used in the core products, outer packaging materials also have a significant effect on the overall sustainability of cosmetic products. A brief supportive research has been dedicated to sustainable packaging options for cosmetic products that are available in the literature. For bio-based cosmetic products to be considered completely healthy and environmentally sustainable, packaging materials used in the products should also be equally sustainable or bio-based. Bioplastics are increasingly preferred as packaging materials instead of conventional plastics. Additionally, glass, metal, wood, and paper are other sustainable packaging materials preferred in bio-based cosmetics. Some of the biomaterials studied in this thesis are also usable as packaging materials, however, these experiments are slightly new, and further research and applications are needed for the development and more common use of these materials as packages.

It should be noted that this thesis has some limitations: during the literature review research, not all the resources about biomaterials in cosmetics have been covered, and only the most present and relevant sources have been added to the findings. Google Scholar was the only platform that was used, so sources from other databases such as Scopus and Web of Science may include additional diverse findings that may support or oppose the findings presented in this study. Likewise, patents listed in this thesis are also exemplary, which means not all patents granted about biomaterial-based cosmetics are covered. Moreover, the comparative review in the development status section only considered the environmental impact of biomaterial production, without the consideration of other criteria. Sustainability comments and comparisons on these biomaterials are therefore limited to water and carbon footprint. Additionally, carbon and water footprint data was not possible to be retrieved from available

sources, so, evaluation and comparison of these materials could not be carried out precisely. Finally, information related to the industry examples including company names, products, and business models is mostly taken from non-scientific web sources such as company and commercial websites, news, and blog posts, which may lead to questioning of source reliabilities.

This study forms a detailed comprehensive report on biomaterials in cosmetics, which can be a groundwork for future studies related to this topic. Further research could focus on the impact of replacing biomaterials with conventional chemicals on Life Cycle Assessment. Furthermore, comparative and more quantitative studies may be carried out for several different biomaterials, as in this thesis, but with more criteria than just carbon and water footprints, such as level of recyclability, biodegradability, or landfill, so that it could be possible to examine more precisely which material has significant advantages over others. Finally, future case studies can focus on other important aspects related to bio-based brands and products, such as consumer perceptions, company incentives quantitative results of footprints, and other sustainability scales. Hereby, more developed and sustainable product formulations can be obtained, in addition to defining more appropriate processing technologies and satisfying customer expectations more effectively.

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Appendix 1

MATERIAL	ORIGIN	PROS	CONS	COSMETICS APPLICATIONS	EXAMPLES (Brands)
CHITIN	Animal	Abundant in nature, high biodegradability and biocompatibility	Low awareness, animal wellfare concerns, chemical processing needed	Sunscreens, antiaging face creams, lotions and skin cleansers	Primex, Kristen Ess, Herbal Essences, Briogeo, Aussie, Babington, Hair Food, Tigi, Vernon Francis, Philosopy, St. Yves, Murad LLC
HONEY	Animal	No need of chemical processing, high trust from society, high nutritional value	Slightly costly, animal cruelty concerns, allergies, toxicity may emerge	Moisturizers, anti-acne products, anti-aging creams, sunscreens, after-sun creams, lip balms, hair products	Bee Cosmetics, Panier de Sans, Farmacy, Lancôme, L'Oréal, Guerlain, Sunday Riley, Laura Mercier
SNAIL SLIME	Animal	Proven and certified safety, trust from traditional uses, low environemntal impact, high biodegradability	Price is comparatively high, risks and concerns over cruelty, not yet very common in markets	Anti-aging, anti-cellulite, anti-acne products, moisturizers, sunscreens, hair products, skin healing lotions and exfoliators	MyAnisha, Nuvò Cosmetic, Royer Cosmétique, Lumea, Nume-Lab, Wonder Company, Benton, Cosryx, Coxir, Mizon, Skin79
MILK	Animal	Proven safety, trust over traditional use, abundant, less need of chemical processing, high biodegradability	Perishable, concerns over animal-based materials in cosmetics, trends towards vegetal milks	Body lotions, moisturizers, anti-acne and anti-aging products, toners, cleansers, wound healing, hair products	Nurst, Asian Beauty Essentials, Korres, Kate Somerville, MooGoo, Oskia and Freeset
SILK	Animal	High biodegradability and compostability, safe to as a skin care material	High costs and sensitivity of material and processing methods, not yet common in markets, concerns over animal cruelty	Body lotions, moisturizers, anti-aging products, sunscreens, hair care products, lipsticks, eyeshadows, mascaras, nail polishes	This is Silk, Tatcha, Evolved by Nature, Silk Therapeutics, Eighteen B, Dermalogica, Alpha-H, Peter Thomas Roth, Dr. Dennis Gross
COFFEE	Plant	High nutritional value on byproducts and waste, safe and trusted material, many green processing methods available	Few researches about negative effects of caffein in topical applications, relatively high carbon and water footprint	Moisturizers, sunscreens, anti-cellulite and anti-aging products, hair growth and care products	Kaffee Bueno, Tom Ford, Origins, Sephora, La Roche Posay, The Ordinary, Marc Anthony, The Body Shop, Paula's Choice, Drunk Elephant, Nykaa, The Sugar, Mcaffeine

Table 39: Biomaterials Recap

Appendix 1

MATERIAL	ORIGIN	PROS	CONS	COSMETICS APPLICATIONS	EXAMPLES (Brands)
TEA	Plant	Abundant and low-cost material, safe and trusted by traditional uses, wastes are valuable in terms of bio-active compounds	Processes mostly require chemical use, lack of reasources about green methods, high carbon and water footprint	Sunscreens, sebum control, wound healing, anti-acne and anti-aging products, hair growth and care products	Teology, Earth to Skin, Miloon, MiiN, Lotus Botanicals, Neogen, TonyMoly, Kumiko, Fresh, Kiehl's, L'Occitane, Elisabeth Arden, Mario Badescu, Byroe, Origins, Tree of Life
ALOE VERA	Plant	Trust from traditional uses, safe, green processing methods available, wastes are rich of bio-active compounds	Allergies may happen, green processing methods can be costly	Make-up bases, lipsticks, creams, sunscreens, cleansers, anti-acne and anti-aging products, after-shave lotions, hair growth and care products	Aloe Vera Cosmetics, RAWW Cosmetics, Pharmas Natur, Sephora, Dove, Kiehl's, SkinCeuticals, Mario Badescu, Humphreys, Vacation, Kinlo, Seven Minerals
CUCUMBER	Plant	Abundant and low-cost, proven safety, trust by public, high biodegradabilty and water content, low carbon and water footprint	More research may be needed regarding the use in skin diseases	Moisturizers, sunscreens, anti-aging products, cleansers, exfoliators, skin barrier protectors, anti-acne products	Garnier, Herbal Essences, Lush, Kiehl's, Mario Badescu, Peter Thomas, Sephora, Boots, Bioderma, Pixi, Burt's Bees, The Body Shop, Glow Recipe, Farmacy, Tula
CACAO	Plant	Safe and trusted, high availability of nutritient-rich byproducts and waste, high biodegradability, soil valorization by cacao plantation	Chemical requirements in processing methods, relatively high water footprint	Moisturizers, anti-aging products, oils, make-up produtcs, sunscreens, anti-cellulite creams, hair growth and care products	100% Pure, All Thing O'Natural, Too Faced, Lush, Fresh, Colorbar, Dot & Key, The Lip Balm Company, The Beauty Co, Perricone MD, Balmyard
EUCALYPTUS	Plant	Safe and trusted, very low carbon footprint, non-chemical processing methods are available	Not very widespread in cosmetics, more reseach may be needed, some processing methods are not very sustainable	Anti-acne products, moisturizers, sebum regulators, exfoliators, sunscreens, hair lotions	100% Pure, Liage, Nabila K, Molton Brown, Necessaire, Yuzu, Noshinku, Salt & Stone, Grove Co., Mrs. Meyer, Little Moon
BANANA	Plant	Abundant and low-cost, trust by public, wastes rich of bio-active compounds, low carbon and water footprint, high biodegradability	Processes may require chemical additions, wastes are not utilized as much as fruit itself, more research is needed about wastes	Moisturizers, creams, lotions, sunscreens, anti-acne products, wound healing, hair care products	Kadalys, The Body Shop, Lush, Sephora, Ole Henriksen, SkinFood, TonyMoly, Boots, Glow Recipe, Lanolips, Drunk Elephant

Table 39 (continued): Biomaterials Recap

Appendix 1

MATERIAL	ORIGIN	PROS	CONS	COSMETICS APPLICATIONS	EXAMPLES (Brands)
PINEAPPLE	Plant	High nutritional value on waste, low-cost material, high biodegrability, abundant	Few research about the cosmetic use of pineapple, need of chemical process to obtain bromelain	Skin cleansers and peelings, skin whitening products, anti-wrinkle creams, serums, sunscreens, skin brightening products	Garnier, Glow Recipe, Herbivore, Too Faced, Pacifica, Shaffali and Juice Beauty
CITRUS FRUITS	Plant	Huge available waste for use, full of fundamental vitamins and minerals for skin health	No research about possible negative effects, chemical processes are generally needed for essential oil extraction	Vitamin serums, skin cleansers, oil-balancing face and hair products, sunscreens	Vita Lake, Circcell, Clarins, The Body Shop, Ole Henriksen, Vitaskin, Burt's Bees, Pixi, MAC, The Body Deli, Neutrogena, Herbal Essences, Molton Brown, Malin, Goetz
BLUEBERRY	Plant	Safe and trusted, very low carbon and water footprint, high biodegradability	Perishable bio-active compounds, relatively lower production volume, processing may not be completely sustainable	Cleansers, creams, scrubs, anti-acne products, sunscreens, skin barrier protectors, make-up products, moisturizers, vitamin serums	Fruida, 100% Pure, Sephora, Neve Cosmetics, Dr. Botanicals, Pupa, Farmacy, Glow Recipe, Truly and Too Faced
COCONUT	Plant	Low-cost, abundantly harvested and nontoxic, non-chemical process of production of material, highly trusted	Slight allergies may happen to specific consumers, not many research about potential negatives	Moisturizers, shampoo, conditioners, body lotions, lip balms, nail polishes, makeup and mouth care products	Rabiah, RAWW, Coconutoil Cosmetics, Herbal Essences, OGX, The Body Shop, Sol de Janeiro, Huda Beauty, Coco & Eve and Aveda
OLIVE	Plant	Abundant and low-cost material, traditional and non-chemical processing methods, safety is proven, trust from traditional uses	Few researches about byproduct and waste products regarding processing methods and safety, relatively high water footprint of olive oil	Moisturizers, sunscreens, body creams, skin cleansers, anti-aging and anti-imperfection products, hair care	Olivella, Olive Oil Skincare Company, Herbolive, Idea Toscana, ORS Hair Care, Garnier, The Body Shop, Clarins, Kiehl's,
FUNGI	Other organisms	High biodegradability and compostability, low-cost material, abundantly available, highly trusted by consumers	Not applicable for all fungi because of toxicity, mild allergies can happen, chemical process may be needed	Skin whitening and anti-wrinkle creams, sunscreens, face creams and body lotions	Shroom Skincare, Symrise, Sawubona, Blu Beryl, Origins
ALGAE	Other organisms	Abundant in nature, very high nutritional content & benefits	Costly application, less producers of algae, limited research about negativities	Moisturizers, body lotions, shampoo and conditioner	Dove, L'Oreal Paris, Nykaa, Algenist, Osea, Jenelt

Table 39 (continued): Biomaterials Recap