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Review

Bioferments and Biosurfactants as New Products with Potential Use in the Cosmetic Industry

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Abstract: The cosmetics industry is one of the fastest growing markets in terms of searching for new ingredients. Recently, there has been a growing interest in products made during fermentation, which are being introduced into cosmetics with increasing frequency, creating a market that emphasizes the positive image of healthy, environmentally friendly components with a positive effect on skin. Scientists mainly focus on examining biological activity as well as the impact on changes in the production of bioactive ingredients in various plant species undergoing fermentation. The studies show that bioferments have scientifically proven anti-aging and anti-inflammatory effects, among other skin benefits. Due to the increasing emphasis on environmental protection, ecofriendly compounds are being sought. This group includes surfactants, which are also obtained by fermentation. Plant-based and microbial biosurfactants, due to their multifunctional properties, such as detergency, emulsifying, foaming, moisturizing, and antibacterial activity, can replace chemical surfactants in many skincare formulations. This review focuses especially on elucidating the importance of the bioferments and biosurfactants and their potential in the cosmetic industry.

Keywords: fermentation; bioferment; biosurfactant; ferment filtrate; cosmetic; biological activity

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1. Introduction

The global cosmetics market is projected to reach US$ 523.5 billion by 2028 [1]. Personal care cosmetics, such as hair and skin care products, shower and bath products, oral hygiene products, deodorants, and shaving products, comprise the category that has the largest market share. Climate change and progressive environmental pollution, and, above all, increasing public awareness of the dangers resulting from the use of chemical substances, will continue to force scientists to put an enormous effort into creating health-friendly and safe cosmetic raw materials [2].

Bioferments are innovative ingredients obtained from natural raw materials by a fermentation process with the use of appropriate strains of microorganisms, i.e., *Saccharomyces cerevisiae*, *Bacillus subtilis*, and *Lactobacillus* species. During the fermentation process, complex structures of compounds are transformed into simpler forms, which can have increased efficiency, higher transepidermal penetration, and better bioavailability and biocompatibility. Fermentation of plant extracts, apart from increasing the biological activity of the substances, may result in the formation of organic acids that are energy substrates for skin cells and have a chelating effect that can reduce metal toxicity. Moreover, the fermentation process influences the production of bioactive compounds, e.g., polyphenols, amino acids, and proteins. Thanks to these advantages, appropriately composed cosmetic

compositions containing bioferments may positively affect the condition of problematic skin and improve the natural balance of the skin microbiome [3,4].

Disruption of the skin barrier is a common challenge for cosmetologists and dermatologists. This problem concerns skin affected by dermatoses, from the use of inappropriate cosmetics, but also by the aging processes occurring in the body. In recent years, a huge variety of products for the care of hypersensitive skin has appeared, some of them concern cosmetics with bioferments intended for people with a damaged skin barrier [4]. Currently, studies are focused on obtaining new bioferments from various plant species and testing them for their anti-wrinkle, antioxidant, UV protective, and anti-inflammatory activity [5–10]. Additionally, bacterial ferment lysates are also used in cosmetic products and have scientifically proven anti-aging, anti-inflammatory, or melanogenesis-inhibiting effects (Figure 1) [11–15].

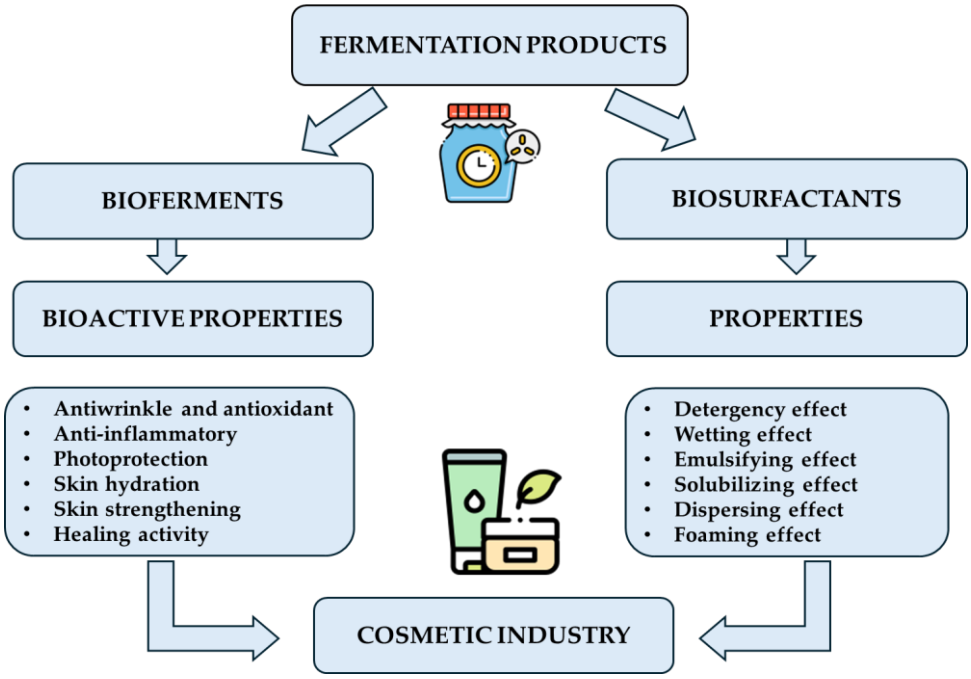

Figure 1. Comparison of the use of bioferments and biosurfactants.

Another interesting product used in modern cosmetics is the surfactants obtained through the fermentation process. Surfactants are the main ingredients of most household chemicals (washing and cleaning agents) as well as products for hygiene and body beautification. About 50% of chemical surfactants on the market are of petrochemical origin [16]. Currently, efforts are being made to replace synthetic surfactants with their ecological (natural) equivalents. Biosurfactants reduce the surface and interfacial tension of liquids, undergo micellization above critical micellar concentration (CMC) and, importantly, are produced from renewable raw materials (oil-contaminated waste, agro-industrial waste, dairy and sugar industry waste, and animal fat) by bacteria, yeasts, fungi, or directly by plants (e.g., saponins) [17]. The physicochemical properties of biosurfactants are analogous to the synthetic surfactants, but they are characterized by high biodegradability, lower toxicity, low irritation potential, and better compatibility with the skin. The production of biosurfactants uses less water and produces less carbon dioxide. The product has greater foaming capacity, starts working at lower temperatures, does not contain preservatives, and does not cause allergies. Post-production waste can be used as feed additives [17,18]. The term "biosurfactants" is also used for surfactants obtained through enzymatic synthesis. They are used in oil extraction, cosmetic applications, pharmaceutical formulations, agrochemistry, land bioremediation, and household chemicals (Figure 1) [17,19].

This review summarizes the information on the history, preparation, and properties of bioferments and biosurfactants, with particular emphasis on collecting current knowledge about their scientifically proven properties and potential use in cosmetic preparations.

2. Bioferments

2.1. History of the Use of Fermented Products

Fermented products have traditionally been used mainly in food. Fermented drinks such as wine, beer, and mead were consumed in ancient times by the Egyptians. Examples of other fermented foods are the tofu, tempeh, natto, bread, kefir, and cheese used in many cultures [18]. Currently, fermentation processes are used not only by the food industry, but also by the pharmaceutical, cosmetic, chemical, textile, and energy industries. Fermentation processes are ecological due to the small number of by-products and waste, and thus reduce greenhouse gas emissions [20].

In the 1970s, *Galactomyces* ferment filtrate was introduced by the Japanese cosmetic company SK-II and patented as Pitera™, a key skin care ingredient. This bacterial ferment was used after the observation that the hands of women making sake were smooth and youthful looking, so the potential of yeast fermentation by-products was investigated. Pitera™ is rich in nutrients such as vitamins, amino acids, and minerals and has gained popularity for its potential skin benefits [21].

Since the promotion of *Galactomyces* ferment filtrate, new bio-ingredients have been developed and their biological activities have been tested. The interest of researchers and cosmetic brands has increased not only in regard to bacterial filtrates but also the fermentation processes of plant material, which have been carried out in order to check the greater ability to produce biologically active compounds and thus increase the biological effect [22].

2.2. Methods of Obtaining Ferment Filtrate

Fermentation is becoming more and more popular in creating new ingredients for cosmetic products. This process is used to increase the biochemical and physiological activity of the substrate. High-molecular weight compounds are transformed into low-molecular weight compounds under the influence of fermentation. This increases the compatibility of the given components. Special strains of microorganisms (yeast, bacteria, and fungi) are used to ferment plant-based raw materials. The selection of the strain influences the formation of the desired products. The fermentation process causes the release of smaller molecules that can bind with active compounds in cosmetics, with potential effects including their increased absorption through the skin. Examples of fermentation products are malic, fumaric, and citric acids [5]. The fermentation process involves two main factors: the first factor is the type of microorganisms used and the second factor is the substrate (Table 1). In the fermentation process, the influence of temperature, pH, and time is also of significance [23].

2.2.1. Bioferments

Bioferments are made mainly from plant-based raw materials. The first stage of bioferment formation is the extraction of selected dried and powdered plant material using a solvent (e.g., water or ethanol), and a specified time. Then the extract is filtered and concentrated, among other procedures, using a rotary vacuum evaporator. Bacteria are grown on appropriate media. The extract is introduced into the bacterial suspension and incubated under appropriate conditions (i.e., time, temperature, access, or lack of oxygen). Then, the post-fermentation solution is centrifuged; the supernatant is collected, filtered, and concentrated using a vacuum evaporator, then freeze-dried and stored at 20 °C [24]. Directions and general mechanisms of biological activity of bioferments are presented in Table 1.

2.2.2. Bacteria Ferment Lysate

To obtain the bacteria ferment lysate, bacterial strains are inoculated in appropriate fermentation medium. Bacterial strains are cultured at a specific time and temperature, usually room temperature or 37 °C, and the duration is at least 48 h. Then the bacterial cells are centrifuged and freeze-dried. The next stage is suspending in deionized water and disruption using a high-pressure homogenizer. The lysates are collected by centrifugation and filtration [25,26]. These compositions obtained from fermentations are called postbiotics (inanimate microorganisms and/or their components that confers a health benefit). On the other hand, probiotics are live microorganisms, which, when administered in adequate amounts via topical application, have interesting properties for skin quality [4]. Directions and general mechanisms of biological activity of bacteria ferment filtrate are presented in Table 2.

2.3. Biological Activity of Bioferments

2.3.1. Anti-Wrinkle and Antioxidant Activities

Pham et al. [5] conducted studies on the effect of fermented black ginseng on procollagen type I, matrix metalloproteinases (MMP-1, MMP-2, MMP-9) and tissue inhibitor of metalloproteinase-2 (TIMP-2). The studies were carried out on human fibroblast cell lines (HS68). Fermented black ginseng was obtained by steaming and drying fresh material and then treated with *Saccharomyces cerevisiae*. The studies showed that at concentrations < 10 µg/mL it had no cytotoxic effect, while concentrations up to 100 µg/mL were safe for the eyes in the EpiOcular-EIT kit test. Fermented black ginseng at concentrations of 0.3 to 10 µg/mL increased the expression level of procollagen type I and decreased the level of MMP-1. Additionally, at a concentration of 10 µg/mL it reduced the expression levels of MMP-2 and MMP-9. The study reported the potential use of the fermented black ginseng in anti-wrinkle preparations (Table 1) [5].

A clinical study was conducted to examine the anti-wrinkle and skin whitening effects of cream with 1% fermented black ginseng. The study involved 23 subjects, who applied the test cream to one half of their faces and the placebo cream to the other half. After 8 weeks, a reduction in the visibility of wrinkles and skin brightening were observed on the side where the tested cream was used. In order to understand the mechanism of action, an in vitro study was also performed on human fibroblast CCD-986sk and mouse B16F1 melanoma cells. Various concentrations of fermented black ginseng were tested and collagen synthesis in CCD-986sk cells was significantly improved. Additionally, at a concentration of 30 µg/mL, inhibition of collagenase and matrix metalloproteinase-1 (MMP-1) was observed in comparison to the controls. Melanin synthesis in B16F1 cells was reduced after treatment with all tested concentrations of fermented black ginseng [27].

Zagórska-Dziok et al. [7] conducted studies on the effect of *Cornus mas* fruit ferment on anti-aging parameters. The ferment was created by extraction with water for 24 h. Then, the extract was filtered and fermented. Sugar, SCOBY (symbiotic culture of bacteria and yeast), and kombucha starter were added to the extract. The fermentation process lasted 14 days. Then, the bioferment was filtered through sterile gauze. The ferment showed higher contents of loganic acid, secoxyloganin, and cornuside than the extracts. In vitro tests on keratinocytes (HaCaT) and fibroblasts (BJ) indicated that the extracts and ferment had no cytotoxic effect on the used cell lines. Collagenase and elastase inhibition tests showed the inhibiting effect of both the extracts and the ferment; however, a higher increase in inhibition was shown for the ferment (Table 1) [7].

Ziemlewska et al. [9] conducted a studies on the influence of fermentation time of *Ilex paraguaiensis* St. Hil. leaves (Yerba Mate) on antioxidant capacity, and collagenase and elastase activity. The ferment was obtained by preparing an infusion of Yerba Mate. The cooled infusion was filtered through membrane filters. Tea fungus, and kombucha were then added to the solution. The fermentation process lasted 7, 14, 21, and 35 days at room temperature. After the specified time, the ferment was filtered and evaporated under reduced pressure at 40 °C. Fluorometric Collagenase Inhibitor Screening Kit and neutrophil

elastase (NE) kit were used for the study. The ferments, especially after 14 and 21 days of fermentation, showed a strong ability to inhibit (approximately 40%) collagenase and elastase (Table 1) [9].

Kim et al. [28] conducted a study of the antioxidant effect of the obtained ferment from *Hordeum vulgare. L. paraplantarum* (AMI-1101), *L. plantarum* (AMI-1103), and *L. brevis* (AMI-1109) were used in the fermentation process. DPPH (2,2-diphenyl-1-picrylhydrazyl) and ABTS (2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) tests showed a greater antioxidant capacity of ferment than the extract itself. Particularly the highest antioxidant activity was detected for the ferment obtained using *L. paraplantarum* (AMI-1101). Additionally, the tested ferment increased production of hyaluronic acid (HA), aquaporin 3 (AQP 3), and filaggrin (FLG) (Table 1) [28].

The anti-aging potential of red ginseng and its ferment obtained using *L. brevis* were compared. The bioferment showed a higher concentration of flavonoids, polyphenols, and uronic acid, which resulted in higher antioxidant activity. Tyrosinase and elastase inhibition studies showed higher activity in favor of the bioferment. In a skin irritation test performed on guinea pigs, 10% red ginseng and 10% bioferment were characterized as practically non-irritating. These results suggested that the red ginseng ferment presented anti-aging properties with high safety of use (Table 1) [29].

Radix astragali was fermented with *Bacillus subtilis natto* and compared with the unfermented extract. Studies on human dermal fibroblasts (HDF) showed that the ferment enhanced collagen biosynthesis, which is partly due to the induction of mitogenic activity and influenced the regulation of procollagen biosynthesis induced by the expression of TGF-β1. Based on the conducted studies, it can be concluded that the *Radix astragali* bioferment is an ingredient that delays the skin-aging process [30]. Similar studies were carried out on the effect of *Astragalus membranaceus* ferment, obtained with the use of *B. subtilis natto*, on the keratinocyte cell line (HaCaT) and skin fibroblasts (HDF). Bioferment stimulated the growth of keratinocytes and fibroblasts and increased the production of hyaluronic acid (HA). In cells treated with bioferment, the expression of hyaluronan synthase 2 and 3 increased, depending on the dose (Table 1) [31].

The studies of *Fructus arctii* ferment obtained using *Grifola frondosa* were conducted on human fibroblasts (HDF) to assessed anti-aging activity. Bioferment was applied to HDF cells and exposed to UVA radiation. Studies have shown decreased expression of matrix metalloproteinase-1 (MMP-1). Bioferment also stimulated collagen biosynthesis. The studies indicated that *Fructus arctii* ferment may have applications in sunscreen and anti-aging products (Table 1) [32].

Gold et al. [33] conducted studies on the anti-aging effect of creams containing *Macrocystis pyrifera* (macroalga). The fermentation process of *M. pyrifera* combined with other ingredients (such as vitamin E, β-carotene) took 3–4 months. In preclinical studies using skin models and keratinocyte cultures isolated from a 62-year-old female, the ferment demonstrated a type I collagen-strengthening effect. In addition, ferment-treated skin cells migrated faster than untreated cells. Two clinical trials were conducted on a total of 101 women aged 39–75 years. Creams with *M. pyrifera* ferment were applied for a period of 12 weeks. Patients experienced a reduction in erythema, an improvement in various skin parameters (i.e., fine lines and wrinkles, redness, skin texture, tone, radiance, and firmness), as well as an increased levels of hydration and reduced transepidermal water loss (TEWL) were reported (Table 1) [33].

Ziemlewska et al. [34] examined the anti-aging effect of fermented leaf extracts of *Rubus fruticosus* L., *Vaccinum myrtillus* L., *Ribes nigrum* L., and *Fragaria vesca* L. Fermentations were carried out using kombucha starter cultures. Assessment of collagenase and elastase inhibition was performed using a fluorometric kit. The study showed that kombucha ferments from studied leaves contribute to the inhibition of collagenase and elastase activity. The study conducted on five volunteers showed that all tested extracts and ferments showed a reduction in TEWL levels, an increase in skin hydration levels, and had

a beneficial effect on skin pH. The tests were performed using an MPA adapter (Courage + Khazaka Electronic) [34].

2.3.2. Protective Effect against UV Radiation

Studies conducted on the peel of *Passiflora edulis* Sims fermented with *S. cerevisiae* showed protective abilities against the negative effects of UV radiation. The fermented peel had more bioactive compounds and higher antioxidant activity. Moreover, studied ferment significantly influenced the cellular pro-inflammatory factors (i.e., heme oxygenase, interleukin-1, interleukin-8, and tumor necrosis factor α) and skin barrier-related factors (i.e., kallikrein-related peptidase 7, filaggrin, aquaporin, and caspase 14) and regulated the proteins associated with the skin barrier by inhibiting activation of the PI3K/AKT/mTOR signaling pathway (Table 1) [8].

The influence of aqueous extract from *Citrus unshiu* peel fermented by *Schizophyllum commune* on human skin fibroblasts (HDF) exposed to UVA radiation was investigated. The results showed reduced expression of MMP-1 in a dose-dependent manner of bioferment. The UVA-induced increase in β-galactosidase (related to skin aging) was reversed by 45%. Additionally, fermented *C. unshiu* peel extract increased collagen biosynthesis in fibroblasts (Table 1) [35].

Studies have shown that fermentation of *Jasminum sambac* flower with *L. rhamnosus* GG increases the viability of fibroblasts exposed to UVB and H_2O_2 radiation, along with reduction of cytotoxicity, intracellular ROS production, and inhibition of collagen degradation in human dermal fibroblasts (HS68). The studies suggested that the *J. sambac* flower ferment may be a component of protection against skin photodamage (Table 1) [36].

2.3.3. Anti-Inflammatory Activity

Tang et al. [10] conducted studies on the effect of ferment from *Dendrobium officinale* obtained with the participation of various strains of microorganisms (*Lactibacillus plantarum* CCFM8661, *L. reuteri* CCFM8631, *L. helveticus* M10, *L. rhamnosus* CCFM237, *Lactilactobacillus sakei* GD17-9, *L. casei* CCFM10 73, *Bacillus subtilis* CCFM1162, *Bacteroides cellulosilyticus* FTJSI-E-2, *B. stercoris* FNMHLBEIK-4, and *S. cerevisiae* HN7-A5) on HaCaT and RAW 264.7 cells. First, SDS (sodium dodecyl sulfate) was applied to the tested cells to damage the skin barrier and cause irritation. The use of both, unfermented and fermented extracts attenuated cell damage. Fermented extracts had higher protective properties. Ferment produced by *L. reuteri* CCFM8631 resulted in the highest cell viability of HaCaT. Additionally, LPS (lipopolysaccharide)-induced inflammation was induced in RAW 264.7 cells, which also increases the level of NO (nitric oxide). Fermented extracts, especially from *L. reuteri* CCFM8631, *L. plantarum* CCFM8661, and *L. casei* CCFM1073 fermentation remarkably decreased the NO content. The performed analyses indicated the *L. reuteri* CCFM8631 strain as the most optimal in terms of number of living bacteria, polysaccharide yield, and cell culture experiment results. Then, CCFM8631 bioferment was tested in vivo and showed anti-inflammatory effect in the skin tissue of the experimental mice (Table 1) [10].

Ziemlewska et al. [9] conducted a study on how the fermentation time of leaves of the *Ilex paraguaiensis* St. Hil. (Yerba Mate) influenced its anti-inflammatory properties. The study was carried out using spectrophotometric methods to determine lipoxygenase inhibition. Both the ferments and the extract itself showed lipoxygenase (LOX) inhibition. The anti-inflammatory properties of the analyzed samples depended on their concentration and the time of the fermentation process. The highest inhibition was obtained for ferments obtained after 14 and 21 days (Table 1) [9].

2.3.4. Wound-Healing Activity

The studies conducted by Zagórska-Dziok et al. [7] assessed the effect of the extract and ferment of *C. mas* (obtained after using symbiotic culture of bacteria, yeast, and kombucha starter) on the migration and proliferation of keratinocytes and fibroblasts. At a concentration of 1000 g/L during 24 h of incubation, migration and proliferation

were stimulated by the extract and the ferment. The ferment, due to higher content of phytochemicals, had a stronger effect compared to the extract (Table 1) [7].

Tang et al. [10] conducted in vivo studies on pathogen-free BALB/c male mice in which skin damage was induced after the use of 2,4-dinitrofluorobenzene (DNFB). An ointment, with *Dendrobium officinale* ferment obtained with the use of *L. reuteri* CCFM8631, with shark squalene, elmulsifier (Montanov S), glycerin, and nipagin ethyl ester, was prepared. In vivo studies showed that the ferment reduced of transepidermal water loss (TEWL), skin epidermal thickness, IL-6 concentrations, and enhanced the expression of filaggrin, thus improve DNFB-induced skin damage (Table 1).

Shi et al. conducted a study on the effects of aloe vera fermentation gel on recurrent aphthous stomatitis. The study was conducted on 35 patients who were divided into two groups. The first group used aloe vera fermentation gel, and the remaining group used chitosan gel. Patients applied the gel after each meal (three times a day) until healing. The study showed faster healing after using aloe vera fermantation gel (4–6 days after application), while, in the group using chitosan gel, it took 7–10 days. In addition, the use of aloe vera fermentation gel reduced the number of harmful bacteria in the oral cavity including, among others: *Actinomyces*, *Granulicatella* and *Peptostreptococcus* [37].

2.3.5. Strengthening and Protection of the Skin Barrier

The effects of *Saccharomyces*/rice ferment filtrate on skin barrier function in vitro (normal human epidermal keratinocytes) and in vivo (clinical testing) was evaluated. The study was conducted on 30 participants who applied a lotion containing *Saccharomyces*/rice ferment filtrate and sunscreen product to one side of their face for 28 days. The studies showed that *Saccharomyces*/rice ferment filtrate improves the skin barrier function by increasing the expression of tight junction (TJ) proteins, such as claudin-1, claudin-4, and occludin, and reducing photoaging and its synergy with sunscreen products (Table 1) [38].

Albouy et al. [39] investigated the effect of fermented *Aframomum angustifolium* on a 3D bioprinted skin equivalent. The ferment was created by mixing ground seeds with the nutrient solution and adding a complex of microorganisms containing *Komagataeibacter*, *Gluconobacter*, *Acetobacter*, *Saccharomyces*, *Torulaspora*, *Brettanomyces*, *Hanseniaspora*, *Leuconostoc*, *Lactobacillus*, and *Schizosaccharomyces*. After 10 days, the medium was collected and filtered. After treatment with bioferment, the skin bioprinting model showed better hydration, higher mitotic activity, better dermal-epidermal connectivity, and higher formation of the dermal–epidermal junction. In addition, increased collagen levels and reduction in overall laxity in dermis were observed. Tests of the content of compounds in the bio-fermented *Aframomum angustifolium* extract showed the presence of phenolic acids such as lactic, gluconic, succinic acid, and glycosylated flavonoids (Table 1) [39].

2.3.6. Hair Growth Activity

Nam et al. [40] studied the influence of *Bacillus*/*Trapa japonica* fruit extract ferment filtrate on human hair follicle dermal papilla (HDP) cells proliferation. In addition, ex vivo experiments were performed. To obtain the ferment, *T. japonica* was subjected to hot water extraction and then mixed with glucose, yeast extract, and soytone. Next, microorganisms such as *Bacillus methulotrophicus* and *Bacillus subtilis* were added. Fermentation lasted 72 h, followed by centrifugation and filtration to remove any microorganisms. The fermented *T. japonica* extract was sequentially separated into hexane, CH_2Cl_2, EtOAc, N-BuOH, and water layers. The study reported the presence of numerous peptides and five unknown fractions in the filtrate. The ferment filtrate extract stimulated the proliferation and migration of human hair follicle dermal papilla cells through the Akt/ERK/GSK-3β signaling pathway. In addition, type I 5α-reductase inhibition, enhanced angiogenesis, and decreased apoptosis in HDP cells were observed. Also, ex vivo model confirmed hair growth activity. This study suggested that *Bacillus*/*Trapa japonica* fruit extract ferment filtrate may be a potential treatment for alopecia (Table 1) [40].

Table 1. Directions and general mechanisms of biological activity of bioferments.

Activity	Plant Species	Bacterial/Fungi/Yeast Strain	Mechanism of Action	Ref.
Anti-wrinkle and antioxidant activities	Black ginseng	*Saccharomyces cerevisiae*	- increases the type I procollagen expression levels in the human fibroblasts	[5]
			- decreases the expression levels of matrix metalloproteinases	[27]
	Cornus mas fruit	Symbiotic culture of bacteria and yeast, kombucha starter	- collagenase and elastase inhibition	[7]
	Ilex paraguaiensis	Tea fungus and kombucha	- collagenase and elastase inhibition	[9]
	Hordeum vulgare	*Lactobacillus paraplantarum*, *L. plantarum* *L. brevis*	- increases production of hyaluronic acid, aquaporin 3, and filaggrin	[28]
	Red ginseng	*Lactobacillus brevis*	- heightens concentrations of flavonoids, polyphenols, uronic acid - inhibits tyrosinase and elastase	[29]
	Radix astragali	*Bacillus subtilis natto*	- increases expression of type I and type III procollagen and TGF-β1 - stimulates procollagen biosynthesis	[30]
			- stimulates growth of keratinocytes and fibroblasts - stimulates hyaluronic acid production	[31]
	Fructus arctii	*Grifola frondosa*	- decreases expression of MMP-1 - stimulates collagen biosynthesis	[32]
	Macrocystis pyrifera	ni *	- reduces erythema - improves various visible skin-aging parameters - increases the level of hydration - reduces TEWL	[33]
	Rubus fruticosus L., *Vaccinum myrtillus* L., *Ribes nigrum* L. and *Fragaria vesca* L.	kombucha starter cultures	- inhibits collagenase and elastase - reduces TEWL - increases skin hydration levels - has a beneficial effect on skin pH	[34]
Protective effect against UV radiation	*Passiflora edulis*	*Saccharomyces cerevisiae*	- reduces the cellular secretion of pro-inflammatory factors - regulates the content of skin barrier-related proteins	[8]
	Citrus unshiu	*Schizophyllum commune*	- reduces MMP-1 expression - provides photoprotection - increases collagen biosynthesis in fibroblasts	[35]
	Jasmine sambac	*Lactobacillus rhamnosuus* GG	- reduces intracellular ROS production - inhibits collagen degradation in human dermal fibroblasts (HS68)	[36]
Increasing skin hydration	*Aframomum angustifolium*	*Komagataeibacter*, *Gluconobacter*, *Acetobacter*, *Saccharomyces*, *Torulaspora*, *Brettanomyces*, *Hanseniaspora*, *Leuconostoc*, *Lactobacillus*, *Schizosaccharomyces*	- improves hydration - increases mitotic activity of the epidermis - improves dermal–epidermal connectivity - increases collagen levels - reduces laxity	[39]
Anti-inflammatory activity	*Dendrobium officinale*	*Limosilactobacillus reuteri*	- improves cell viability - decreases nitric oxide (NO) content - reduces IL-6 levels	[10]
	Ilex paraguaiensis	Tea fungus and kombucha	- inhibits lipoxygenase (LOX)	[9]

Table 1. *Cont.*

Activity	Plant Species	Bacterial/Fungi/Yeast Strain	Mechanism of Action	Ref.
Wound healing activity	*Cornus mas* fruit	Symbiotic culture of bacteria and yeast; kombucha starter	- increases migration and proliferation of keratinocytes and fibroblasts	[7]
	Dendrobium officinale	*Limosilactobacillus reuteri*	- reduces TEWL and skin epidermal thickness - increases expression of filaggrin	[10]
	Aloe vera gel	*Lactobacillus plantarum*	- shortens healing time in recurrent aphthous stomatitis - reduces harmful oral bacteria	[37]
Protection of the skin barrier	*Aframomum angustifolium*	*Komagataeibacter*, *Gluconobacter*, *Acetobacter*, *Saccharomyces*, *Torulaspora*, *Brettanomyces*, *Hanseniaspora*, *Leuconostoc*, *Lactobacillus*, *Schizosaccharomyces*	- improves hydration - increases mitotic activity of the epidermis - improves dermal–epidermal connectivity - increases collagen levels - reduces laxity	[39]
	Rice	*Saccharomyces*	- increases expression of claudin-1, claudin-4, and occludin - reduces photoaging	[38]
Hair growth activity	*Trapa japonica*	*Bacillus methulotrophicus*, *Bacillus subtilis*	- stimulates the proliferation and migration of human hair follicle dermal papilla (HDP) cells - inhibits type I 5α-reductase - enhances angiogenesis and decreases apoptosis in HDP cells	[40]

* ni—no information; Ref., References; TEWL, Transepidermal Water Loss.

2.4. Biological Activity of Bacterial Ferment Filtrate

2.4.1. Anti-Wrinkle Activity

A study on the impact of the use of *Galactomyces* ferment filtrate (Pitera®) on skin aging in 86 women was conducted. Female volunteers were treated with three skin care products that contain *Galactomyces* ferment filtrate (SK-II Facial Treatment Essence, SK-II Cellumination Essence, and SK-II Skin Signature Cream) for a period of 12 months. Skin parameters were measured at 2, 8, and 12 months. Studied products significantly increased skin hydration as well as reduced TEWL. The tests were performed in 2010 to see the changes that occurred with age. Parameters measuring wrinkles, spots, and roughness also improved after the 11-year interval [11].

Kim et al. [12] conducted a study on the effects of *Epidermidibacterium keratini* (EPI-7) ferment filtrate on skin aging. The study involved 55 women divided into different age groups. For 3 weeks, participants applied a preparation containing *Epidermidibacterium keratini* (EPI-7), ferment filtrate, or placebo to a randomly selected side of the face. The parameters were measured using the Courage Khazaka Electronic system. Studies have shown that the use of EPI-7 fermentation filtrate resulted in significantly greater improvements in barrier function, skin elasticity, and skin density compared to the placebo group [12].

Gedik [6] examined the use of cream with *Alteromonas* ferment extract, a by-product of fermantation *Alteromonas macleodia* (a marine bacteria). The tests were performed on the human dermal fibroblasts from a donor aged of 30 years. The cream was not cytotoxic at concentrations lower than 0.5% and, at concentrations of 0.1% and 0.2%, increased collagen synthesis in fibroblasts by 57% and 67%, respectively [6].

2.4.2. Anti-Inflammatory Activity

Rhee et al. [13] conducted in vitro tests and clinical trials to show activity of the *Cutibacterium acnes* subspecies defendens strain XYCM42 ferment filtrate. In vitro studies on human keratinocytes and fibroblasts showed decreased expression of several inflammatory

cytokines, including IL-1α, IL-6, IL-8, and TNF-α. Additionally, studies on cultured human peripheral blood mononuclear cells showed a tendency towards reduction in the expression of inflammatory genes (IL-1β, IL-6, and interferon-γ). Moreover, a clinical trial using preparations based on XYCM42 was performed. Two studies were conducted, one 3-week pilot study (n = 10) and an 8-week main study (n = 121), and studied products were XYCM42 ferment-based serum, moisturizer, and sunscreen. Clinical observation has shown that the cosmetics containing XYCM42 increase skin hydration, reduce erythema, have a soothing effect on the skin, and regulate sebum secretion [13].

Galactomyces fermentation filtrate has been shown to be agonist of aryl hydrocarbon receptor (AHR), that play an important role in the regulation of metabolic processes and immune response. Transcriptomic analysis of *Galactomyces* fermentation filtrate-treated human keratinocytes showed increased expression of cytochrome P450 1A1 (*CYP1A1*), which is responsible for AHR activation. The studies indicated an increase in the expression of genes responsible for epidermal differentiation (*SPRR1A* and *SPRR1B*), wound healing (*SERPINB2*) and maintaining the integrity and function of the skin barrier (caspase-14 and claudins). Moreover, *Galactomyces* fermentation filtrate reduced the expression of genes associated with inflammation, such as *CXCL14* (C-X-C motif chemokine ligand 14) and *IL6R* (interleukin-6 receptor). It was suggested that *Galactomyces* ferment filtrate may have potential soothing and anti-inflammatory effect in dermatoses treatment [41].

Choi et al. [42] conducted tests on the anti-inflammatory activity of 10 strains of lactic acid bacteria extracts obtained by lysozyme treatment. *Bifidobacterium lactis*, *B. longum*, *Lactobacillus acidophilus*, *L. brevis*, *L. casei*, *L. plantarum*, *L. reuteri*, *L. rhamnosus*, *Weisella cibaria*, and *W. Hania* were used. The tests were carried out on male mice in which erythema on the ear was induced by the phorbol 12-myristate 13-acetate (PMA). PMA dissolved in acetone and combined with an equal volume of test solution in ethanol was applied topically to the mouse's ear to develop edema. Among the tested bacteria lysate, *B. lactis* ferment showed the greatest anti-erythema (73.4%) and anti-edema (67.1%) effects [42].

2.4.3. Strengthening and Protection of the Skin Barrier

Wang et al. [43] investigated the influence of *Bifida* fermentation lysate (obtained by fermentation and extraction of *Bifidobacterium*) on the skin barrier using in vitro models. Application of the lysate increased the level of the skin's barrier gene (*FLG*, *LOR*, *IVL*, *TGM1*, and *AQP3*) and the antimicrobial peptides gene (*CAMP* and *hBD-2*) in human HaCaT cells. Thus, *Bifida* fermentation lysate may be responsible for skin barrier resistance. In antioxidant tests, such as DPPH, ABTS, hydroxyl, and superoxide radical scavenging activity assay, studied lysate showed dose-dependent radical scavenging ability. Moreover, the inhibition of intracellular production of ROS and MDA in HaCaT cells was reported. *Bifida* fermentation lysate also reduced the secretion of IL-8 and TNF-α and gene expression level of cyclooxygenase-2 (COX-2) in THP-1 macrophages [43].

Studies on the effect of *Vitreoscilla filiformis* bacterial lysate on the normal human epidermal keratinocytes (NHEK) confirmed improvement in the skin barrier function through the increasing the level of tight junction proteins, such as filaggrin, involucrin, claudin-1, and zonula occludens-1 in NHEK cells [44].

Studies showed that, after the addition of *Saccharomycopsis* ferment filtrate, keratinocytes had higher expression of tight junction proteins, which determined tissue homeostasis. In keratinocytes treated with studied ferment mRNA and proteins levels of claudin-1, claudin-3 and 4, occludin and ZO-1 were increased. The increase in the value of TER (transepithelial electrical resistance) confirmed the influence of studied ferment on the barrier function of the epidermis. The studies confirmed that *Saccharomycopsis* ferment filtrate improve the condition of skin by modulating and strengthening the skin barrier function [45].

Cui et al. [25] performed tests on lysates of *Lacticaseibacillus rhamnosus* VHProbi® E06 (E06) and *L. Paracasei* VHProbi® E12 (E12) and reported the protective effect on HaCaT cell viability. *S. aureus* ATCC 25923, H_2O_2, and ultraviolet-B (UVB) radiation were used to

induce the deterioration of cell viability. Both lysates increased proliferation and reduced toxicity caused by the previously mentioned factors. Subsequently, the lotion formula with four fermented lysates (E06, E12, *Lactiplantibacillus plantarum* VHProbi® E15, and *Lactobacillus helveticus* VHProbi® Y21) were prepared. Lotion containing 3% tested lysates was used in clinical trials (on 52 participants). The assessment was carried out with VISIA®-CR (Canfield Scientific Inc, Parsippany, NJ, USA) and CK®-MPA (Courage+Khazaka electronic GmbH, Köln, Germany) devices. In addition, Burden of Sensitive Skin questionnaire (BoSS) and self-assessment questionnaire were performed. Data from the study showed that at day 30, there was a significant decrease in TEWL, redness, and increase in hydration compared to baseline measurements. BoSS and self-assessment questionnaires also substantiated that the studied subjects noticed positive change in their skin conditiom [25].

Clinical trials have been conducted on ferment lysates of *Lacticaseibacillus rhamnosus* IDCC 3201. This study aimed to determine whether the cream containing the bacteria ferment lysate improves the barrier function of the skin. The study was performed on 24 women aged 20–70. The TEWL and the skin hydration tests were performed and the beneficial effects for skin barrier function were confirmed. In patient surveys, respondents also positively assessed the improvement in skin hydration [26].

Miyamoto et al. conducted a study on the protective effect of a cream with a moisturizer containing a *Galactomyces* ferment filtrate on the skin. Mask wearing to protect against COVID-19 caused various facial skin damage. A total of 20 women participated in the study. Parameters such as facial pore size, skin redness, skin hydration, and TEWL were measured. The first phase included not wearing a mask (2 weeks); in the second phase, individuals wore a mask 6 h per day, and during the next 2 weeks, wore a mask with the topical application of a *Galactomyces* ferment filtrate-containing cream. Wearing the mask resulted in increased redness, pore size, and TEWL. However, the use of a moisturizing cream with *Galactomyces* ferment filtrate improved the tested parameters [46].

2.4.4. Protective Effect against UV Radiation

Studies have been carried out to prove that *Lactococcus* ferment lysate and *Bifida* ferment lysate in 5% aqueous solution and 100% concentrate have antioxidant properties in DPPH tests. Moreover, *Lactococcus* ferment lysate contained in the emulsion had an absorption capacity in the UVB area (SPF 4.75) comparable to the standard chemical UV filter homomenthyl salicylate (SPF value 4.45), and in the UVA range it showed higher protective properties. However, *Bifida* ferment lysate did not show significant protective properties against UVA and UVB radiation [47].

2.4.5. Anti-Melanogenic Activity

Wu et al. [14] conducted studies on *Bifidobacterium longum* strain, ZJ1, isolated from a Chinese centenarian to assess the anti-melanogenic activity of the extracts of ZJ1. Results indicated that both the whole lysate and the bacterial lysate of ZJ1 ferments inhibited melanin production stimulated by the α-melanocyte-stimulating hormone (α-MSH) in B16-F10 cells (murine melanoma cell line). Moreover, a reduction in melanin content in zebrafish embryos has been demonstrated [14].

2.4.6. Anti-Acne Activity

The studies performed by Cui et al. [15] showed anti-acne effect of *L. plantarum* VHProbi® E15 ferment lysate. In patients with mild and moderate acne, a lotion with 8% bacterial ferment lysate was used for a period of 4 weeks. The study was conducted on 22 adult participants. First, the inhibition activity of *C. acnes* ATCC 11827 and ATCC 6919 by *L. plantarum* VHProbi® E15 was tested using a double-layer agar plate assay and agglutination test. The test showed that the *L. plantarum* VHProbi® E15 strain could inhibit the growth of *C. acnes* and did not show self-agglutination after 72 h of incubation. Visia®-CR system and CK-MPA® system (CK-MPA10, Courage + Khazaka electronic GmbH, Köln, Germany) were used in the clinical study. After 2 weeks of treatment, improvement in acne

lesions was observed and persisted until the end of the study. After 4 weeks of treatment, transepidermal water loss and sebum production in patients were significantly reduced compared to baseline values [15].

2.4.7. Anti-Redness Activity

A study was also conducted on the impact of the use of *Galactomyces* ferment filtrate (Pitera®) on improving skin quality. Young Japanese women (n = 104) participated in the study. The study lasted 4 weeks, during which *Galactomyces* ferment filtrate was administered twice a day. Each participant measured skin parameters using portable and self-guided facial skin imaging device (eMR Pro, eHealth Solution Ltd, Wokingham, Great Britain). It was shown that the use of *Galactomyces* ferment filtrate reduced skin redness, pore size, and skin roughness [21].

Table 2. Directions and general mechanisms of biological activity of bacteria ferment filtrate.

Activity	Bacterial Strain	Mechanism of Action	Ref.
Anti-wrinkle activity	*Galactomyces* ferment filtrate	- improves skin hydration - reduces TEWL - reduces wrinkles, spots and skin roughness	[11]
	Epidermidibacterium Keratini ferment filtrate	- improves barrier functions, skin elasticity, and density	[12]
	Alteromonas ferment extract	- increases collagen synthesis	[6]
Anti-inflammatory activity	*Cutibacterium acnes subspecies defendens strain* XYCM42 ferment filtrate	- decreases IL-1α, IL-6, IL-8, and TNF-α levels - reduces expression of IL-1β, IL-6, and IFN-γ genes - improves skin hydration - reduces erythema - regulates sebum secretion	[13]
	Galactomyces fermentation filtrate	- reduces expression of inflammatory genes - increases expression of genes responsible for epidermal differentiation, wound healing, and skin barrier integrity	[41]
	Bifidobacterium lactis	- has anti-erythema and anti-edema effects	[42]
Strengthening and protection of the skin barrier	*Bifida* fermentation lysate *(Bifidobacterium)*	- increases the level of the skin's barrier gene - inhibits intracellular production of ROS and MDA - reduces secretion of IL-8 and TNF-α - reduces gene expression level of COX-2	[43]
	Vitreoscilla filiformis	- increases the level of tight junction proteins	[44]
	Saccharomycopsis fermentation filtrate	- increases expression of tight junction proteins - increases TER (transepithelial electrical resistance)	[45]
	Lacticaseibacillus rhamnosus VHProbi,® *Lactobacillus paracasei VHProbi*®	- increases proliferation in HaCaT cell line - reduces toxicity caused by damage factors - decreases TEWL, increases hydration	[25]
	Lacticaseibacillus rhamnosus IDCC 3201	- reduces TEWL - increases skin hydration	[26]
	Galactomyces ferment filtrate	- reduces facial pore size, skin redness, and TEWL - minimizes mask-related skin damage	[46]
Protective effect against UV radiation	*Lactococcus* ferment lysate	- increases absorption capacity in the UVB area (SPF 4.75)	[47]
Anti-melanogenic activity	*Bifidobacterium longum* strain bacterial lysate	- decreases melanin production	[14]

Table 2. *Cont.*

Activity	Bacterial Strain	Mechanism of Action	Ref.
Anti-acne activity	*Lactiplantibacillus plantarum VHProbi® E15*	- inhibits growth of *C. acnes* - reduces acne lesions - reduces TEWL - reduces sebum production	[15]
Anti-redness activity	*Galactomyces* ferment filtrate	- reduces skin redness, pore size, and skin roughness	[21]

Ref., References; IFN-γ, interferon-γ.

2.5. Application of Bioferments in the Cosmetics Industry

Recently, there has been increase in researching bioferments and their use by the cosmetics industry. This is evidenced by the large number of cosmetics used substances produced in the fermentation process, as well as the numerous patents filed regarding these substances. The information about kind of bioferment available in cosmetics are included in the coordinated by European Union's special cosmetic ingredients database—CosIng [48]. By entering the word "ferment" into this database, about 2.240 examples are obtained. This proves the extensive use of these substances in this industry. Table 3 shows examples of cosmetic products available on the global market containing bioferments.

Among the patents related to bioferments, there are distinguishing methods for obtaining ferments of milk obtained from soybeans and their use in skin care products and also oat fermentation liquor [49,50]. In 2020, a bioferment obtained by fermentation of *Saccharomyces cerevisiae* from the above-ground parts of *Citrus aurantium* was patented and can be used for anti-aging products [51]. Moreover, methods for obtaining bioferment and extract from *Rhodiolae* radix using yeast have been patented. This product has anti-aging and skin-brightening properties [52]. Lim et al. in 2021 patented a cosmetic composition containing fermented rice by-product extract or a fraction thereof as an active ingredient with antioxidant, skin-whitening, and wrinkle-reducing properties [53].

This section presents examples of randomly selected patents. Their number is enormous and constantly growing, which means that the cosmetics industry is very interested in these products.

Table 3. Examples of some cosmetics with bioferments.

Producer	Country of Origin	Trade Name	Cosmetic Form	The Kind of *Ferment* in the Composition of the Cosmetic (INCI)	Properties of the Cosmetic According to the Producer	Ref.
Venn	Republic of Korea	Probiotics Cica Complex Biome Booster	face serum	*Saccharomyces* ferment, *Lactobacillus* Ferment Lysate, *Galactomyces* Ferment Filtrate	- sooths and repairs dry skin - moisturizes and deeply hydrates the skin - improves skin's elasticity	[54]
Abib	Republic of Korea	Rice Probiotics Overnight Mask	mask	*Lactobacillus*/Rice Ferment	- protects irritated skin	[55]
Scinic	Republic of Korea	Bio Collagen Firming Lotion	lotion	*Lactobacillus*/Soybean Extract Ferment Filtrate	- improves skin's elasticity and refines skin's texture	[56]

Table 3. *Cont.*

Producer	Country of Origin	Trade Name	Cosmetic Form	The Kind of *Ferment* in the Composition of the Cosmetic (INCI)	Properties of the Cosmetic According to the Producer		Ref.
Purito	Republic of Korea	Fermented Complex 94 Boosting Essence	essence	*Bifida* Ferment Lysate, *Saccharomyces*/*Viscum Album* (Mistletoe) Ferment Extract, Saccharomyces/*Imperata Cylindrica* Root Ferment Extract, *Lactobacillus*/Soybean Ferment Extract	-	moisturizes rough skin	[57]
Babor	Germany	Pollution Protect	ampoules	*Bifida* Ferment Lysate	-	protects against external factors	[58]
Biotherm	France	Biomains	cream	*Vitreoscilla* Ferment Extract	-	prevents premature ageing and strengthens nails	[59]
Bio Balance	Turkey	Dermasebum Purifying Skin Care Cream	cream	*Saccharum Officinarum* Ferment Extract	-	reduces the production of excess sebum and minimizes enlarged pores, blackheads, and shine	[60]
Yope	Poland	Vitamin C + Kakadu Plum Serum	serum	*Lactobacillus*/Acerola Cherry Ferment, *Lactobacillus*/*Punica Granatum* Fruit Ferment Extract, *Leuconostoc*/Radish Root Ferment Filtrate, *Lactobacillus* Ferment Lysate	-	prevents premature ageing	[61]
Bielenda	Poland	Water Balance Cleansing Face Wash Gel	Cleansing gel	*Saccharomyces*/Barley Seed Ferment Filtrate	-	cleans and refreshes dry, poorly moisturized, dehydrated skin	[62]
Domohorn	Japan	Intense Hydrator	serum	*Lactobacillus*/Changbai Ginseng Ferment Filtrate, *Saccharomyces*/*Ipomoea Batatas* Ferment Extract	-	hydrates the skin	[63]
Circulove	Finland	CLEAN|Micellar Cleanser & Toner	toner	*Lactobacillus*/Oat Ferment Extract Filtrate, *Lactobacillus* Ferment Lysate	-	purifies and refreshes	[64]
Elizabeth Arden	USA	Prevage Anti-Aging Overnight Cream	cream	*Lactobacillus*/Lemon Peel Ferment Extract	-	intensively moisturizes skin overnight	[65]

Ref., References.

3. Biosurfactants

3.1. History of Biosurfactants

Surfactants are characterized by an amphiphilic structure of molecules, with both a hydrophilic part (head) and hydrophobic (tail). Thus, these structures are able to accumulate at the surface separating two immiscible physical phases. Due to migration, the concentration of surfactant particles at the phase boundary is greater than in solution.

By reducing the free energy of a given physical system, decrease in surface tension (ST) between two immiscible phases occurs. A good surfactant can lower ST of water from 72 to 35 mN/m [66]. The most commonly used surfactants are sodium lauryl sulfate (SLS) and ammonium lauryl sulfate (ALS). The hybrophobic tail of surfactants is composed of long-chain fatty acids. According to the ability of the hydrophilic head to dissociate in aqueous solutions, there are non-ionic and ionic (cationic, anionic, and amphoteric) surfactants. Most chemical surfactants are made from petroleum-based raw materials [67]. Biosurfactants are produced by plants, bacteria, yeast, and filamentous fungi [2]. Biosurfactants, as amphiphilic molecules, also possess a hydrophilic part (e.g., amino acids, proteins, mono and polysaccharides, phosphates, and alcohols) and a hydrophobic part (e.g., long-chain fatty acids, hydroxyl fatty acids, and α-alkyl-β-hydroxy fatty acids) [66]. Biosurfactants are classified according to the producer microorganism, molecular weight, properties, and mechanism of action (Table 4). According to the chemical structure, biosurfactants are mainly divided into glycolipids (composed of carbohydrates and long-chain aliphatic or hydroxyaliphatic acids); lipopeptides (composed of the amino acids and carboxyl and hydroxyl groups of a 14-carbon fatty-acid chain); and polymeric biosurfactants (lipid-protein and lipid-polysaccharide complexes) [67,68]. Differences in the structure of biosurfactants may depend on the type of medium used to grow the microorganisms (type of substrates, amount of macro, micro, and trace elements), and the growth conditions (i.e., temperature and aeration) [69]. The content of carbohydrates in the microbial medium plays the greatest role in biosurfactant production, because they participate in the formation of both the hydrophilic and hydrophobic part of the compound [67,68]. Studies have also shown a positive relationship between the efficiency of the biosurfactant synthesis process and the presence of hydrophobic carbon sources [70]. The first known biosurfactants were rhamnolipids synthesized by *Pseudomonas aeruginosa*, lipopeptide synthesized by *Bacillus subtilis*, and mannosylethitritol produced by *Candida*. In recent years, the main interest of research were rhamnolipids and sophorolipids obtained from bacteria and yeast, while the use of fungi as a source of biosurfactants is negligible [67].

3.2. Classification of Biosurfactants

3.2.1. Plant-Based Biosurfactants

A separate group of biosurfactants with a glycosidic structure are saponins composed of a hydrophobic aglycone (sapogenin) and a hydrophilic sugar fragment (glycone). Due to the aglycone structure, they are divided into steroidal saponins and triterpenoid saponins. Saponins are natural non-ionic surfactants, thus they have wide range of surfactant properties, including emulsification, foaming, micellization, and detergency [71]. Saponins are secondary compounds derived from different parts of plants, such as roots, stems, bark, leaves, seeds, and fruits. Their source of origin may also be marine animals, e.g., star fish or sea cucumber [72,73]. Saponins are used as emulsifiers in alcohol industry, as solubilizing agents for vitamins and minerals, and as food additives for the reduction of lipids absorption [74]. Saponins are also used as surfactants in cosmetics (i.e., hair cleanser, hair conditioner, hair oil, hair dye, and bathing soap) [75,76].

The main plants rich in saponins are: *Glycyrrhiza glabra*, *Yucca schidigera*, *Quillaja saponaria*, *Polygala* spp., *Hedera helix*, *Primula* spp., *Trigonella foenum-graecum*, *Aesculis hipocastanum*, *Panax ginseng*, *Saponaria officinalis*, and *Calendula officinalis* [75,76].

The major commercial sources of saponins added to ointments, creams, deodorizers, and hair-shampoos are *Yucca schidigera*, and *Quillaja saponaria*. *Yucca schidigera* contains steroid-like saponins, which have anti-inflammatory, antioxidant effects. *Quillaja saponaria* contains a high percentage of triterpene saponins, which have anti-inflammatory and analgesic effects [77,78].

3.2.2. Microbial Biosurfactants

The division of microbial biosurfactants, based on differences in their structure, is presented in Table 4. The two groups of these compounds are: low-molecular surfactants

(e.g., glycolipids, lipopeptides, fatty acids), which strongly reduce surface and interfacial tension, and high-molecular surfactants (containing, among others, polysaccharides, proteins, lipids), capable of creating stable oil in water emulsions (Table 4) [79].

Table 4. Division of microbial biosurfactants according to their chemical composition and particle size.

Class		Biosurfactant	Microrganism	Ref.
Low molecular weight BS	glycolipids	rhamnolipids	*Pseudomonas* sp., *Bacillus* sp., *Renibacterium* sp., *Enterobacter* sp., *Acinetobacter* sp., *Planococcus* sp., *Lysinibacillus* sp., *Microbacterium* sp., *Stenotrophomonas* sp.	[69,80–88]
		trehalipids	*Rhodococcus erythropolis*, *Arthrobacter* sp.,*Mycobacterium* sp., *Corynebacterium* sp, *Bordetella hinizi-DAFI*	[87,89]
		sophorolipids	*Candida* sp., *Trichosporon asahii*, *Starmerella bombicola*, *Wickerhamiella domericqiae*	[87,90–93]
		cellobiozolipids	*Ustilago maydys*	[94]
		mannosyl erythritol lipids	*Pseudozyma* sp., *Ustilago scitaminea*, *Candida* sp.	[95,96]
		mannosyl mannitol lipids	*Pseudozyma* sp.	[97]
High molecular weight biosurfactants	Lipoproteins	surfactin	*Bacillus subtilis*	[98,99]
		subtilisin	*Bacillus subtilis*	[87]
		serravetin	*Serratia marcescens*	[100]
		iichensin	*Badllus licheniformis*	[100]
	Fatty acids and phospholipids		*Corynobaderium lepus*, *Nocardia erytbropolis* *Adnetohader* sp., *Penidlliurn* spiculisporum	[100]
	Polymeric biosurfactants	emulsan	*Acinetobacter*, *calcoaceticus BD 4l3*	[101]
		alasan	*Adnetobader radioresistens KA 53*	[89]
		biodispersan	*Adnetobader calcoaceticus A2*	[87]
		mannoprotein	*Saccharomyces cerevisiae*	[102]
		liposan	*Candida lipolitica*	[89]
	Molecular biosurfactants	fimbriae, outer membranevesicles (OMV)	*Acinetobacter calcoaceticus*	[100]
		PM-factor	*Pseudomonas marginalis*	
		whole cells	*Cyanobacteria*	

3.3. Application of Selected Biosurfactant Cosmetics

Due to low toxicity to humans and the environment, as well as many other desirable features related to surface properties, such as detergency, emulsifying, solubilizing, wetting, dispersing, and foaming effects, biosurfactants have many applications in industry. Rhamnolipids, which are the most commonly used group, can be used as ecological emulsifiers that are less toxic than chemical ones. They have also been used in many cosmetic formulations such as: moisturizers, anti-wrinkle and anti-ageing creams, nail care products, baby products, toothpastes, contact lens solutions, insect repellents, and lipsticks [103,104]. Mannosylerythritol lipids are the active ingredients to prevent skin roughness [105].

3.3.1. Glycolipids

Glycolipids are the most common and desirable group of biosurfactants in the cosmetic and pharmaceutical industry, with great stability throughout a wide range of pH levels,

temperatures, and salinities [71]. They are composed of carbohydrate moieties bonded to fatty acid chains of varying lengths. Among the glycolipids, the most commonly used are rhamnolipids, trehalolipids, mannosyl erythritol lipids (MELs), mannosyl mannitol lipids (MMLs), cellobiozolipids, and sophorolipids [106].

3.3.2. Sophorolipids

Sophorolipids are composed of sophorose (glucose dimer) and a long chain of hydroxyl fatty acids. Sophorolipids are mainly produced by the yeasts, including *Candida bombicola*, *Starmerella bombicola*, *Candida bogoriensis*, and *Candida apicola* [91,107].

The sophorolipids lactone form has activity typical of biocides, which have better foaming ability and better solubility in water than the lactone form. In cosmetic formulations, sophorolipids have antibacterial properties (against *Pseudomonas aeruginosa*, *Staphylococcus aureus*, and *Escherichia coli)* and antifungal activity (against *Candida albicans* and *Aspergillus niger*). Sophorolipids were shown to be effective inhibitors of bacterial pathogens when combined with antibiotic or natural compounds such as sericin and calcium alginate, without any side effects on skin tissue. They can potentially be used in the local treatment of bacterial wounds and skin lesions, because of shortening the wound healing time [108,109] and antiviral, antibacterial, antimicrobial, and antibiofilm properties [92,110]. The long carbon chains of sophorolipids (22 carbon chains) had the strongest antibacterial effects on the tested bacteria *Cutibacterium acne.* They exhibit antibacterial properties against *Propionibacterium acnes* in different plant-based composites pectin and alginate. Sophorolipids derived from hydrolyzed horse oil showed anti-wrinkle effects as well as to improve skin elasticity. They may be useful as emulsifiers for cosmetic and skincare pharmaceutical formulations [111–113]. Sophorolipids are known to be effective in skin delivery of molecules for application in cosmetic and pharmaceutical formulations. They increase the penetration of active components across the skin barrier and improve the skin absorption, for example: lactoferrin [114] or mogrosides V [115].

3.3.3. Rhamnolipids

Another group of biosurfactants are rhamnolipids produced, among others, by strains of *Pseudomonas.* They are characterized by excellent emulsification activity against various oils, ability to clear hydrophobic impurities, and nontoxicity [71]. They are shown to be effective inhibitors of *P. aeruginosa* because they have the potential to facilitate the secretion of psoriasin in epidermal keratinocytes. Psoriasin is an antimicrobial protein produced in response to expression of flagellin by *P. aeruginosa.* Rhamnolipids prevent skin surface colonization by pathogens without altering the normal skin flora and immune cells [116,117]. Additionally, these molecules exhibit proliferative effects on epidermal keratinocytes [116].

3.4. Application of Biosurfactant in the Cosmetic Industry

The cosmetic industry is increasingly using biosurfactants in its compositions. This is influenced by, among others, the lower risk of acute dermal irritation or oral toxicity, while maintaining surface activity, and washing efficiency [71].

There is a growing trend of patenting newly developed biosurfactants, their production methods, and ready-made cosmetic formulas [118–121]. In 2017, methods for obtaining biosurfactants from the *Bacillus* strain were patented [122]. Another patented biosurfactants can self-assemble aggregate into polymers and can be used as micellar structures in topical dermatological products [123]. Suzuki et al. patented an active ingredient of mannosyl alditol lipid (such as MEL and MML) that provided an activator of anti-aging effects [124]. Kitagawa et al. [125] created a cosmetic formula for skin roughness improvement containing a biosurfactant (MEL-A, MEL-B or MEL-C). Kim et al. [126] patented novel compounds having biosurfactant activity that are produced by an *Aureobasidium pullulans* L-3-GPY strain.

Cosmetics containing biosurfactants are available all over the world. Examples of preparations with biosurfactants are presented in Table 5.

Table 5. Examples of some cosmetics with biosurfactants.

Producer	Country of Origin	Trade Name	Cosmetic Form	The Kind of *Ferment* in the Composition of the Cosmetic (INCI)	Properties of the Cosmetic According to the Producer	References
Matsuyama	Japan	Hadauru Moisturising Cleansing Gel	cleansing gel	sodium surfactin	- helps the moisture retaining function of the skin barrier.	[127]
BioAqua	China	Natto Calming & Hydrating Facial Mask	mask	sodium surfactin	- sooths and repairs damaged barrier	[128]
Annemarie Börlind	Germany	Peeling powder	peeling	subtilisin	- removes dead skin cells and activates cell renewal in the skin	[129]
Babor		Enzyme cleansing	cleanser	subtilisin	- cleanses the skin	[58]
Dr Botanicals	Great Britain	Cocoa Noir Sensuous & Indulgent Body Oil	oil	subtilisin	- smooths the skin and corrects visible imperfections	[130]
Elemis		Dynamic Resurfacing Super-c Serum	serum	subtilisin	- brightens the skin	[131]
Mary Kay	USA	Volu-Firm Foaming Cleanser	foaming cleanser	subtilisin	- cleanses skin without leaving it feeling stripped - helps support the skin barrier	[132]
Bk		Acne serum brightening Anti-Pollution	serum	mannosylerythritol lipid	- brightens the skin - prevents acne	[133]
Cipla	India	Excela Lite	cream	mannosylerythritol lipid	- improves skin hydratation	[134]

3.5. Other Uses of Biosurfactants and Their Advantages

Interest in biosurfactants has increased because of their environmental compatibility and versatility in emulsification. The advantages of biosurfactants compared to chemical surfactants are undoubtedly their low toxicity and lack of negative impact on the environment, as well as their biodegradability. Despite many undoubted advantages of biosurfactants over chemical surfactants, the use of these compounds is associated with certain limitations, including a higher price compared to classic surfactants, the risk associated with the use of opportunistic strains of bacteria in the industrial production of biosurfactants, such as *P. aeruginosa* in rhamnolipids, and technical problems with obtaining pure forms of biosurfactants instead of a mixture of compounds. In addition to the possibility of using them in the cosmetics industry as cleansing agents and emulsifiers, biosurfactants can also be used in other areas, such as the food, oil, pharmaceutical, and textile industries, as well as those related to the secondary use of renewable raw materials [71] (Table 6).

Table 6. Other application of biosurfactants in industries.

Industry	Biosurfactant	Applications	Ref.
Petroleum/ Oil Industry	Rhamnolipids Lipopeptide (Surfactin, Lichenysin) Polymeric BS (Emulsan, Alasan)	emulsifiers, demulsifiers, transportation assistant, microbial enhanced oil recovery (MEOR)	[135–140]
Foods	Rhamnolipids Polymeric BS	emulsifiers (also in low fat products), foaming, wetting, solubilizers antimicrobial agents, improvement of texture and creaminess, improvement of shelf-life of starch-containing products,	[103,141–143]
Pharmaceuticals	Lipopeptides (gramicidins and polymyxins) Rhamnolipids	antimicrobial agent, antifungal agent, anti-adhesive agents, anti-cancer agent, antiviral agent, foaming agents, inhibition of fibrin clot formation, stimulation of the autoimmune system, tumor growth inhibition, gene transfection	[104,144]
Envronmental sanitation Agriculture Bioprocessing	Rhamnolipids	degradation and dispersion of different classes of hydrocarbons, emulsification of hydrocarbons and vegetable oils, removal of metals from soil	[103,145–148]
	Trehalolipids	bioavailability of hydrocarbons	
	Sophorolipids	recovery of hydrocarbons from dregs and muds, removal of heavy metals from sediments	
	Polymeric BS	stabilization of hydrocarbon-in-water emulsions	
	Lipopeptides (surfactin)	biodegradation of hydrocarbons and chlorinated pesticides; removal of heavy metals from a contaminated soil, sediment, and water; increasing the effectiveness of phytoextraction	
Textile	Plant-based BS	lubricant, scouring and leveling agent, bleaching assistant, removing the impurities from raw material such as cotton	[149]

3.6. Examples of Other Ingredients of Cosmetic Products Obtaining by Fermentation Process

Ingredients obtained through fermentation are becoming increasingly popular in the cosmetics industry due to their numerous benefits for the skin and the environment. Fermentation products can be found in the group of emollients, hygroscopic substances and NMF (natural moisturizing factor) ingredients, rheology modifiers preservatives, and odor compounds. The most important examples of fermentation compounds products and their descriptions are presented in the Table 7.

Table 7. Other fermentation compounds products used by the cosmetics industry.

Group of Cosmetic Ingredient	Cosmetic Ingredient	Bacterial/Fungi/ Yeast Strain	Description	Ref.
Emollients	Squalane	*Saccharomyces cerevisiae*	A naturally occurring isoprenoid compound. Fermentation of sugar cane with *Saccharomyces cerevisiae* allowed the production of the squalene precursor β-farnesene.	[150]
	Cetyl alcohol/ 1-hexadecanol	*Saccharomyces cerevisiae*	Modified *Saccharomyces cerevisiae*, producing fatty alcohol, were used to produce 1-hexadecanol from xylose.	[151]

Table 7. *Cont.*

Group of Cosmetic Ingredient	Cosmetic Ingredient	Bacterial/Fungi/ Yeast Strain	Description	Ref.
	Vegetable oils	*Pseudozymas yeast* spp.	Fermentation of licorice, artemisia, and shiunko oils, using *Pseudozymas yeast spp*., allowed the creation of emollients containing a higher content of free fatty acids, α-tocopherol, and polyphenols.	[152]
Hygroscopic substances and natural NMF ingredients	Hyaluronic acid	*Bacillus subtilis*	Obtained by fermentation using *Bacillus subtilis*. The polysaccharide was released into the medium and spray dried.	[153]
	Glycerine	*Candida glycerinogenes*	Glycerol production during fermentation using the yeast *Candida glycerinogenes*, isolated from a natural sample in an environment with high osmotic pressure.	[154]
	Lactic acid	*Bacillus coagulans*	Fermentation using corn, cassava, sugar cane, and isolate sugars *Bacillus coagulans.* Fermentation of defatted rice bran with *Bacillus coagulans*	[155,156]
	Butylene glycol/ 1-3-butanediol	*Escherichia coli*	Fermentation of plant dextrose by a modified strain of *Escherichia coli*.	[157]
	Propylene glycol/1,3-propanediol	*Lactobacillus reuteri*	Glycerol and corn alcohol from *Lactobacillus reuteri*	[158]
	Xylitol	Enzyme systems *Candida guilliermondii*	Xylose fermentation by immobilized enzyme systems or *Candida guilliermondii* fungi.	[159]
Rheology modifiers	Xanthan gum	*Xanthomona*	*Xanthomonas* bacteria campestris, which ferment glucose, glucose syrup, corn syrup, or cheese whey in the presence of nitrates.	[160]
	Bacterial cellulose	*Acetobacter xylinum*	Fermentation of mangoes using *Acetobacter xylinum*, under optimized culture conditions.	[161]
	Alginate	*Pseudomonas Azotobacter bacteria* spp.	Naturally found in the cell walls of red and brown macroalgae and in some microalgae. *Pseudomonas and Azotobacter bacteria spp*., are alginate producers.	[162,163]
Preservatives	*Lactobacillus* ferment	*Lactobacillus* spp.	Produces bacteriocins, which, in combination with organic acids, give the formulation antimicrobial properties.	[164]
Odor compounds	Vanillin	*Pseudomonas putida strains*, *Streptomyces setonii*	Conversion of *Pseudomonas strains putida* and *Streptomyces setonii* into ferulic acid, which is then transformed into vanillin.	[165,166]
	α-linolenic	*Botryodiplodia theobromae*	Product of the metabolism of *Botryodiplodia theobromae*, which, after esterification, gives a product with a sweet jasmine scent.	[165]
	Terpenes	*Ceratocystis species*	Produces a variety of terpenes with fruity or floral scents.	[165]

4. Conclusions

Products of plant origin are increasingly used by the cosmetics industry. The use of fermentation products in cosmetics is becoming more and more popular. Fermentation of plant material can contribute to improving the phytochemical content; due to the formation of simpler structures, the bioavailability of these compounds also increases. In addition, research shows mainly anti-wrinkle and antioxidant effects, as well as an ability to strengthen the hydrolipid barrier of the skin. The number of bioferments used in cosmetics is increasing due to the use of different plant materials, as well as different bacterial strains and different fermentation conditions. There is a very large number of products in cosmetic ingredient databases and the number is constantly growing. Biosurfactants produced through fermentation are increasingly used in the cosmetics industry. In times of great interest in non-toxic, natural, ecological, and environmentally friendly cosmetic raw materials, biosurfactants are a very promising group of compounds. However, their commercial, widespread use will only be possible if production prices are comparable to chemical surfactants. Natural products created through fermentation may be a possible hope for the sustainable development of cosmetic products that protect consumers and the environment.

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