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Review Article

Exploring marine-derived bioactives for innovative cosmeceutical applications: A review

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Abstract
The cosmetic industry has experienced remarkable growth in the past decade, witnessing a significant expansion in current market presence and economic impact. Evolving beyond traditional beauty products, the industry has introduced innovative concepts, leading to the emergence of terms such as "cosmeceuticals" to describe products that enhance appearance and offer health benefits. Natural product-based cosmeceuticals, perceived as safe, have garnered considerable attention from the public and research fraternity. Marine resources have unique chemicals and biological qualities that can not be found in terrestrial resources. The demand for cosmeceuticals derived from marine sources has recently increased drastically. This review emphasizes novel chemical molecules derived from marine natural resources, exploring their cosmeceutical potential and elucidating the mechanisms of action (MOA) through which these compounds impact bodily functions and confer associated health benefits. Marine settings hosting a rich biodiversity repository harbor physiologically active chemicals with untapped potential for cosmeceutical and medicinal applications. Marine organisms in cosmetic formulations offer diverse bioactive molecules beyond their conventional use as renewable bulk compounds (e.g., carrageenan and agar). These molecules, such as anti-tyrosinase agents (e.g., kojic acid), antiacne compounds (e.g., sargafuran), Ultraviolet (UV) protectants (e.g., scytonemin, mycosporine-like amino acids), antioxidants, and antiwrinkle agents (e.g., astaxanthin and polyunsaturated fatty acids), play crucial roles as active ingredients in cosmeceuticals. This comprehensive exploration underscores the potential of marine-derived bioactives in shaping the next generation of innovative cosmeceutical formulations, offering a sustainable and effective approach to skincare and beauty.

Keywords: Anti-photoaging activity, Antityrosinase, Antiwrinkle, Cosmeceuticals, Marine-derived compounds

INTRODUCTION

Cosmetics as defined by European regulation no. 1223/2009 are the products designed for external application on the human body with objectives ranging from cleansing, perfuming to protection and appearance enhancement. (Guilleme *et al.,* 2017). Cosmetics are subjected to stringent requirements. Rerequirements.These requirements encompass ensuring the safety of the products, minimizing potential side effects, and substantiating their positive impact on overall well-being. (Kalra *et al*., 2020). The cosmetics market is highly dynamic, witnessing a constant influx of new products at a rapid pace. This continuous innovation has led to the emergence of novel concepts and the introduction of new terminology. One such term is "cosmeceuticals," coined by Kilgman, which combines "cosmetics" and "pharmaceuticals (Kligman, 2005)." Cosmeceuticals refer to cosmetic products that offer benefits similar to those of pharmaceutical drugs (Rashid *et al*., 2023). The term is commonly used in the cosmetic industry, although not recognized by the Federal Food, Drug, and Cosmetic Act (FD&C Act) (https,//www.fda.gov/regulatory-information/laws-enforced-fda/federal-food-drug-and-cosmetic-act-fdc-act). The selection of these substances is attributed to their capability to penetrate the skin and specifically target biological processes such as inflammation, pigmentation, and aging (Dini and Laneri, 2019).

Marine pharmaceuticals have captivated considerable interest in the cosmeceutical industry owing to their distinctive and diverse bioactive constituents. The capacity of marine pharmaceuticals to provide contemporary solutions for a range of dermatological disorders elucidates their significance in the field of cosmeceuticals (Martins *et al*., 2014). These bioactive substances have many biological properties, including anti- melanogenic, antiacne, anti-photoaging, anti-wrinkling, Wound healing and anti-inflammatory, antibacterial, antioxidant, anti-tyrosinase, and anti-aging activities (Fig.1.) (Brunt and Burgess, 2018). They have the potential to offer therapeutic advantages since they can target particular cellular processes and pathways implicated in dermatological disorders (Lim *et al*., 2019). Marine cosmeceuticals are natural health products that, when consumed, can enhance the appearance and functionality of the snails, hair, and skin. These substances are thought to work on the body's aesthetic effects and/or personal cleanliness. Because consumers nowadays are more conscious of the foods they eat and the supplements they take, they are more likely to choose natural products that can enhance and restore health and beauty without any negative effects (Dini and Laneri, 2019).

As a result, marine cosmeceuticals are growing in popularity. Cosmeceuticals are active substances in various formulations, including creams (Zata *et al*., 2020) lotions, and ointments. These ingredients include vitamins, minerals, phytochemicals, and enzymes. These naturally occurring bioactive compounds may be obtained from a variety of sources, including marine life, microbes, and terrestrial plants (Siahaan *et al*., 2022). These compounds can serve a wide range of purposes, some advantageous to human health and can support strong, healthy skin, hair, and nails at the cellular level. Plants grow too slowly in general, and their chemical combination fluctuates according to changes in season to season and region (Siahaan *et al*. 2017). Despite this, plant-derived substances are quite popular and widely utilized in cosmetics. On the other hand, using contemporary aquaculture techniques, marine plants and animals can create chemically distinct biomolecules that are not present in different terrestrial resources and may be grown quickly and affordably in vast quantities (Agrawal *et al*. 2018).

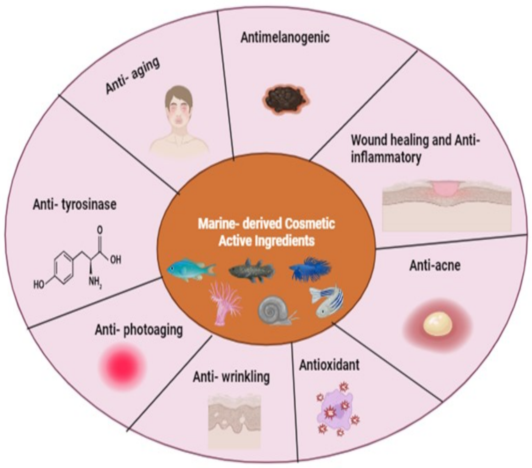


Fig.1. *Use of marine sources for dermatological disorder* (Zata *et al*., 2020)

Marine cosmeceuticals' biological targets and mode of action of drugs

Depigmentation of skin, UV filters, antiinflammatory, antiacne, antiwrinkle, moisturizing, anti-aging, antioxidant, and cytoprotective compounds are all in high demand right now (Carpio *et al*., 2021). The biological-related activities and associated MOA of certain important cosmeceutical and biochemical pathways and target sites are involved in such processes (Sánchez-Suárez *et al*., 2022).

Anti-melanogenic activity

The desire to lighten and make skin tone brighter and eliminate localised hyperpigmentation drives the need for skincare products (Corinaldesi *et al*., 2017). Skin whitening deals with the use of natural or synthetic agents that cause hypopigmentation by lowering the melanin concentration in the skin. This practice can be driven by dermatological necessities such as skin hyperpigmentation caused by autoimmune conditions, exposure to UV radiation, genetic factors, and hormonal changes that can induce an overproduction of melanin in the skin. Synthetic substances that cause a decrease in pigmentation by reducing the melanin concentration in the skin can be used (Babitha and Kim 2011). One or more melanogenic pathway steps, like transfer of melanosome, degradation, and post-transfer pigment processing, may be involved in depigmentation. Avoiding exposure to UV light, blocking tyrosinase enzyme, inhibiting the proliferation and metabolism of melanocytes, or eliminating the melanin itself can all stop the production of new melanin (Pillaiyar *et al*., 2017).

Several mechanisms, including the suppression of the transcription factor linked to microphthalmia, the downstream of melanocortin 1 receptors activity, the disruption of melanosome maturation and transfer, the loss of melanocytes, and the tyrosinase enzyme inhibition, can result in skin lightening. Many depigmenting substances modify skin pigmentation by affecting the activity and transcription of tyrosinase-associated melanogenic enzymes, tyrosinase-related protein-1 (TYRP-1), TYRP-2, or peroxidase. The most frequent and widely used ingredient in skin-whitening cosmetics is tyrosinase inhibition. Due to toxicity, poor stability, limited skin penetration, and low potency, synthetic tyrosinase inhibitors have only seen limited application to date (Masum *et al*., 2019). Since it is commonly accepted that these substances are safer than traditional skin whiteners, researchers have recently focused on substances from marine creatures, particularly phlorotannin like 7-phloroeckol (Fig.2) obtained from brown algae (Azam *et al*., 2017). The concept that active substances are not isolated but instead exist within complex and stable groups of chemicals that reduce their detrimental impacts at the location of application raised safety concerns (Lee *et al*., 2022). Similarly, arbutin,azelaic acid, and kojic acid are found to have anti-melanogenic properties, which help with skin whitening (Fig.2).

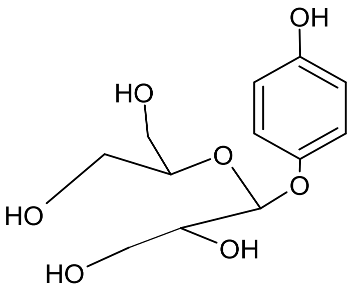
Anti-tyrosinase activity

Melanin acts as a shield against UV rays, and its antioxidant properties protect the skin. This pigment is vital for protecting against sun damage and plays roles in disguising appearance, maintaining body temperature, and working with beauty products. (Chang and Teo, 2016). The skin is constantly exposed to both external and internal environments, and as a result, it rapidly responds to these conditions by altering the pattern of constitutive pigmentation. An imbalance in melanin production, whether too much or too little, goes beyond just cosmetic concerns. Even slight shifts in one's health or exposure to harmful environmental factors can affect skin coloration trends within transitory (like during pregnancy) or long-lasting (such as age spots) and hence address illnesses including lentigo, pregnancy masks, and hyperpigmentation brought on by drug overdoses, whitening cosmetics are also in high demand.

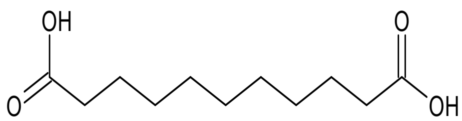
Melanin is produced through specific biochemical processes within melanosomes and organelles in melanocytes. This melanin is later transferred to adjacent keratinocytes to protect against UV radiation. The enzyme tyrosinase plays a key role in the initial stages of this melanin production by converting tyrosine to 3,4-dihydroxy phenylamine (DOPA) and then oxidizing DOPA to dopaquinone (Rodrigues *et al*., 2021). Tyrosinase plays a critical role in producing melanin and controlling skin coloration. Because it is a key enzyme in this process, a common approach in cosmetic skin-lightening treatments is to inhibit or reduce its activity. To prevent the disparity, most studies conducted to assess newer tyrosinase inhibitors use conventional tyrosinase inhibitors that act as positive control, such as kojic acid (Nursid *et al*., 2020). Kojic acid, a fungal metabolite product, is the most extensively studied tyrosinase inhibitor. It is currently used in cosmetics to lighten skin and as a food additive to deter enzymatic browning. Tyrosinase inhibitors are useful for treating several dermatological conditions linked to melanin hyperpigmentation and are essential depigmenting agents in cosmetics (Peng *et al*., 2021).

Anti-aging activity

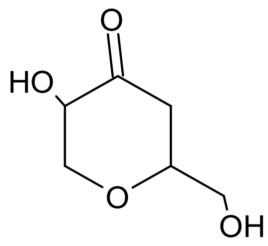
Skin aging involves the deterioration of the dermis, characterized by thinning, dryness, reduced firmness, fragility, enlarged pores, the appearance of fine lines and wrinkles, visible blood vessels, increased transparency, and diminished elasticity (Suh *et al*., 2014). Wrinkles form due to the natural decrease in skin thickness and elasticity with age, along with the distortion of elastic fibres within the skin. Yet, outside influences such as sun exposure, pollution, nicotine, repetitive facial expressions like squinting or frowning, and lifestyle choices, including diet, sleep habits, and overall health, also play a role in aging. Intrinsic aging, on the other hand, is mainly influenced by genetic factors (Brancaccio *et al*. 2022).



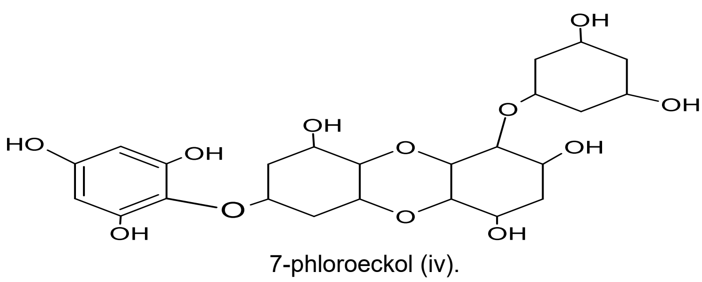
Arbutin (i)



Azelaic acid (ii)



Kojic acid (iii)



7-phloroeckol (iv).

Fig. 2. *Structures of arbutin (i), azelaic acid (ii), kojic acid (iii), and 7-phloroeckol (iv)*

The lamellar barrier shrinks with ageing, reducing the skin's moisture retention capability. Additionally, the aging process involves a decline in collagen production, decreased activity of fibroblasts, and a slower rate of fibroblast renewal. Human skin is a physical barrier against viruses and physical harm, dividing the inside from the outside world (Prastya *et al*., 2020). Certain compounds, both inorganic and organic, like melanin, help regulate protection systems against UV damage. To shield themselves from UV rays, different organisms produce specific substances, for example, plants generate secondary metabolites such as flavonoids, while marine microorganisms in high-sunlight areas create substances like scytonemin, mycosporine-like amino acids (MAAs), and other UV-protective compounds with unidentified chemical structures. Animals, including humans, rely on melanin for UV protection. Beta-carotene is a potent ingredient in preventing the formation of harmful reactive oxygen species (ROS), safeguarding against cellular damage and aging. It's recognized as a key component with anti-aging benefits (Nayak *et al*., 2022).

Anti-photoaging activity,

Dermatophilosis or photoaging can result from prolonged exposure to UV light. The composition of epidermal extracellular matrix (ECM) can be altered due to exposure to UV radiation, specifically UV-A (400 nm–320 nm) and UV-B (320 nm–290 nm) (Kasanah *et al*., 2022). Mottled pigmentation, histological alterations such as altered connective tissue and epidermal thickness, and even skin cancer (melanoma) are frequently mediated by ROS. Numerous issues result from prolonged exposure to ultraviolet (UV) rays and are linked to different pathological effects of skin damage (Chen *et al*., 2019).

Exposure to UV rays can lead to sunburn when melanin does not provide sufficient protection. While limited sun exposure can boost mood and vitamin D production, it can also cause immediate skin issues like burns, thickening, redness, and excessive tanning. Over time, continuous exposure is detrimental, contributing to premature skin aging and increased risk of skin cancer due to UV-induced immune suppression (Hsieh *et al*., 2013). While UV-A predominantly impacts the deeper dermal layer and UV-B targets the outer epidermal layer, both significantly contribute to skin aging. They harm dermal fibroblasts by triggering cytokines, matrix metalloproteinases (MMPs), and mutations in mitochondrial DNA. By reducing antioxidant enzymes & the antioxidant defence mechanism, radiation-induced oxidation may lead to photoaging, which may cause severe oxidative damage, immune modulation, activation of melanin production, and, ultimately, carcinogenesis (Khan *et al*., 2018). Use sunscreen creams that frequently incorporate organic or inorganic filters to prevent the harmful effects of UV exposure. Various natural compounds with photoprotective properties have been studied for innovative technological applications. These include substances like scytonemin sourced from cyanobacteria, mycosporines found in fungi and cyanobacteria, MAAs present in various organisms (Table 1) like cyanobacteria, microalgae, macroalgae, yeast, fungi, sponges, corals, and certain animals, as well as flavonoids from plants and melanin in both humans, other animals, and certain bacterial species (Liu *et al*., 2018).

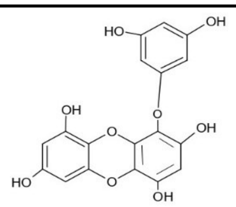
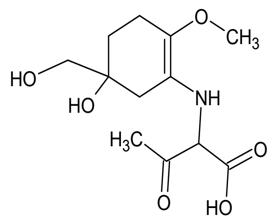
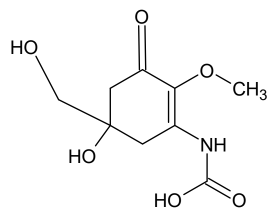
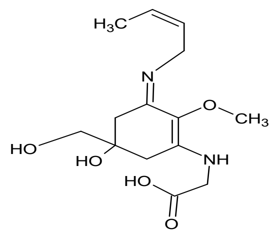
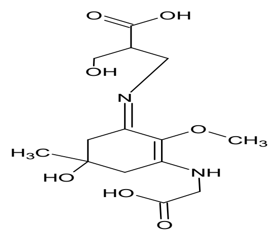
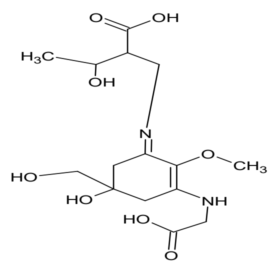
Antiwrinkle activity

The majority of antiwrinkle/antiaging cosmetic formulas include moisturising ingredients to keep the skin hydrated, which is crucial for proper skin function (Shanura Fernando *et al*., 2018). To imitate the skin's natural hydration mechanisms, lipids that prevent water loss or substances that can establish connections with water molecules are applied externally (Kalasariya *et al*., 2022). Trans epidermal water loss (TEWL) is typically reduced to its usual level by using an oil/water emulsion that contains linoleic acid and linolenic acid to hold onto the water in the skin. Currently, researchers are exploring marine microorganism-derived biosurfactants like mannosyl erythritol, rhamnolipids, and sophorolipids for potential use in cosmetics. These substances possess emulsification, solubilization, wetting, foaming, and dispersion properties. They enhance the solubility of hydrophobic components in products and aid in their effective delivery through the skin barrier (Kalasariya *et al*., 2021). These biosurfactants sourced from marine organisms offer benefits over synthetic alternatives because they result in minimal skin irritation, making them ideal for anti-aging treatments (Riani *et al*., 2018). Antiwrinkle activities of some marine-derived compounds are mentioned in Table 2.

Anti-oxidant activity

Antioxidants are essential for cellular defence against aging as they prevent UV-induced reactive oxygen species like superoxide anion (O_2), hydroxyl radical (HR), and H_2O_2 from damaging membrane lipids, proteins, and DNA (Zhong *et al*. 2019). Antioxidants protect the skin from harmful environmental factors like UV rays, cigarette smoke, and air pollution that promote oxidative damage. The so-called "antioxidant therapy" involves consuming nutritional supplements that contain antioxidants to maintain health and stave off various ailments (Tziveleka *et al*., 2021). Enzymatic and non-enzymatic chemicals make up antioxidants, while in humans, plasma and erythrocytes include enzymatic antioxidants like superoxide dismutase (SOD), catalase, the peroxidase glutathione (GSH), reductase of glutathione (RG), & glutathione transferase (GST). Chlorophylls, carotenoids, and analogues of tocopher-

Table 1. Important anti-photoaging activities of marine compounds

S. No.	Compound	Source	Mode of Action	Structure	Reference
1	Eckol	Algae	Eckol has antioxidant qualities, assists in scavenging damaging free radicals in the skin.		(Pallela *et al.*,2010)
2	Mycosporine methylamine-serine	Algae and Cyanobacteria	Skin soothing, UV absorption and Anti inflammatory effect		(He *et al.,* 2022)
3	Mycosporine-glycine	Red algae	DNA damage prevention, Antioxidant properties and reducing damage caused by UV radiation.		(Jun *et al.,* 2020)
4	Palythene	Marine Bacteria	Anti- photoaging through UV protection, Antioxidant properties		(Kim *et al.,* 2012)
5	Shinorine	Microalgae	Antioxidant activity and defiance against photoaging by reducing damage caused by UV Radiation		(Oh *et al.,* 2020)
6	Porphyra-334	coral	Antioxidant activity and protection against photoaging by reducing UV-induced damage to the skin		(Ryu *et al.,* 2014)

ols including vitamin E and isoprenoids are intriguing pigments obtained through marine resources which are naturally occurring antioxidants (Vega *et al*., 2020). Carotenoids are key ingredients in numerous sunscreens because of their antiinflammatory and antioxidant properties. They aid in shielding the skin from UVA-induced reactive oxygen species and enhance skin protection against sunlight. On the other hand, MAAs have a strong antioxidant activity by scavenging superoxide anion, which prevents lipid peroxidation and protects the skin from UV rays. In addition to their thickening and moisturising abilities, algae-derived carbohydrates may also contain anti-oxidant, anti-melanogenic, and anti-aging qualities that are good for skin, making them valuable cosmeceuticals (Vladkova *et al*., 2022). Additionally, the anti-oxidant activities of some marine-derived compounds are shown in Table 3.

Table 2. Important anti- wrinkle activities of marine compound sported

Marine Compound	Source	Mode of Action	Findings	Reference
Fucoidan	Brown seaweeds such as Sargassum sp., Undaria pinnatifida, and Fucusvesiculosus.	Possesses antiwrinkle effects that slow down the skin's breakdown of collagen and elastin fibers by blocking the enzymes collagenase and elastase. It also promotes the formation of collagen and enhances skin hydration.	Based on both in vitro and in vivo studies, fucoidan has been shown to improve skin elasticity, reduce wrinkle depth, and increase skin firmness.	(Fitton *et al.,* 2015)
Collagen peptides	Scales of fish, skin of fish, or other aquatic sources of collagen.	Through simple skin absorption, they stimulate the creation of newly produced collagen fibres, promoting skin suppleness and reducing the appearance of wrinkles.	Clinical reduces wrinkle depth and increases skin moisture and softness.	(Al-Atif, 2022)
Squalene	olive oil, algae, and other marine plant-based oils like shark liver oil.	Moisturizes and protects against free radicals. It enhances skin hydration, offers UV protection, and lessens oxidative stress. Additionally, it encourages skin cell renewal and aids in restoring the skin's normal barrier function.	It has been shown in studies to have the ability to smooth out fine lines, inhibit the development of wrinkles, and enhance skin texture.	(Alves and Kijjoa, 2020)
Astaxanthin	Microalgae that retain astaxanthin have a protective pigment, including Haematococcus pluvialis.	Strong antioxidant that fights free radicals and lessens oxidative stress prevents MMPs, which are responsible for breaking down collagen.	Topical application may boost skin hydration, improve skin suppleness, and reduce the depth of wrinkles.	(Alves and Kijjoa 2020); (Siahaan *et al.*, 2022)
Marine collagen	Scales of fish, skins of fish, and other marine sources of collagen.	Promote collagen synthesis, increase skin suppleness, and minimize the look of wrinkles.	It enhances skin texture and aids in moisture retention.	(Siahaan *et al.*, 2022)
Eicosatetraenoic acid (EPA)	Abundantly present in fish oil, especially those from cold-water fatty fishes.	It has anti-inflammatory and antioxidant properties that can help lessen the oxidative stress and inflammation contributing to wrinkles and skin ageing.	Additionally, it improves skin water retention and also performs barrier function.	(Brunt and Burgess, 2018)
Dermaseptin	Derived from sea frogs' skin secretions.	A peptide with antibacterial and antioxidant effects is referred to as dermaseptin.	It has demonstrated potential anti-ageing effects by increasing skin suppleness, lessening the depth of wrinkles, and speeding up the healing of wounds.	(Navon-Venezia *et al.,* 2002)
Chondroitin sulphate	Derived from marine sources such as shark cartilage.	Through the stimulation of collagen production, inhibition of collagenase activity, and improvement of skin moisture, chondroitin sulphate has antiwrinkle benefits.	Promotes skin firmness to the skin.	(Pai *et al.*, 2017)
Sea cucumber extract	produced by several sea cucumber species.	Bioactive substances found in sea cucumber extract, including peptides, collagen, and antioxidants, support its antiwrinkle efficacy.	It aids in enhancing skin texture, reducing wrinkle formation, and improving skin elasticity.	(Bahrami *et al.,* 2018)

Antiacne activity

Acne vulgaris, generally known as acne or pimples, is the most prevalent skin condition marked by the swelling of the sebaceous glands (Ardiansyah *et al*., 2021). While commonly seen in adolescents, acne can also appear in adults. Various elements, including hormonal changes, microbial factors, and immune responses like androgen-driven oil gland activity, follicular hyperkeratinisation, and inflammation, play roles in acne formation. The bacterium *Propionibacterium acnes* is responsible for the inflammation that leads to the development of inflamed lesions (Pagar *et al*., 2023). Some anaerobic bacteria trigger the release of pro-inflammatory cytokines along with ROS, and excessive production results in a harmful phenomenon that eventually leads to scars. To digest excess of sebum and

Table 3. Important anti-oxidant activities of marine compounds

Marine Compound	Source	Mode of Action	Findings	Reference
Fucoxanthin	Brown seaweeds like Undaria pinnatifida and Hijikia fusiformis.	It reduces oxidative stress, neutralises free radicals, and stops the lipid peroxidation of the skin.	It has antiinflammatory qualities and the ability to increase skin suppleness. It promotes the overall well-being of the skin and provides protection against premature ageing caused by oxidative damage.	(Seth *et al.,* 2021)
Porphyra-334	Porphyria species of red algae.	Absorption of UVB and UVA light aids in defending the skin against oxidative damage brought on by UV radiation.	It has calming effects on the skin and helps to keep it healthy.	(Becker *et al.,* 2016)
Phlorotannin	Brown seaweeds such as Ascophyllum nodosum, Ecklonia cava(EC), and Fucusvesiculosus.	They demonstrate high antioxidant activity through the scavenging of free radicals and the inhibition of oxidative stress. It also has antiinflammatory properties, aids in UV damage prevention, and stimulates collagen production in the skin.	They have been found to support better skin health and skin brightness.	(Rajan *et al.,* 2021)
C-phycocyanin	Blue green algae (e.g., spirulina)	It has antiinflammatory and antioxidant properties. It neutralises free radicals, lowers oxidative stress, and shields the skin from harm caused by the environment.	It increases collagen synthesis and enhances skin suppleness.	(Bannu *et al.,* 2019)
Halogenated compounds	Algae, sponges, and various marine microbes	They can neutralize free radicals, reduce oxidative stress, and shield the skin from harm from the environment.	Some halogenated substances have also shown anti-inflammatory properties and the ability to enhance skin health.	(Shanura Fernando *et al*., 2016)
Bromophenols	Red and brown algae (Rhodophyta and Phaeophyta, respectively) are examples of marine algae.	They have Antiinflammatory and antioxidant characteristics that work well to scavenge free radicals and reduce skin oxidative stress.	The potential of bromophenols to prevent UV-induced ageing and promote skin health has been studied.	(Olsen *et al.,* 2013)
Mero-terpenoids	marine invertebrates, including corals and sponges.	meroterpenoids have significant antioxidant properties. They can neutralise free radicals, lessen oxidative stress, and shield the skin from harm caused by the environment.	These substances have also demonstrated promise for accelerating wound and skin healing.	(Mhadhebi *et al*., 2011)

skin oil, they also release lipases, which in turn trigger a severe local inflammatory response that destroys hair follicles (Mias *et al*., 2023). Consequently, the cosmetics sector has identified inhibiting the growth of P. acne as a key strategy for acne treatment. During research on antibacterial components from aquatic resources to create natural skincare products for acne prevention, Sargafuran (Fig. 3.) emerged with potent antiacne properties against P. acnes, showing a minimal inhibitory concentration (MIC) value of 15 μg/mL. Exploring

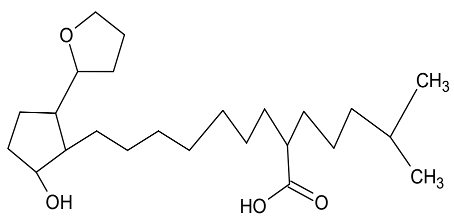


Fig. 3. *Structure of Sargafuran*

chemicals from various algae species could offer promising options for developing skincare products targeting acne vulgaris (Nabiya *et al*., 2022). Antimicrobial activities exhibited by some marine-derived compounds are listed in Table 4.

Wound healing and antiinflammatory activities

The sophisticated and highly controlled wound healing process involves reconstructing injured tissues' anatomical structures and forms. Three phases overlap in it (Park *et al*. 2017).

Proliferative phase- This triggers the release of growth hormones and promotes the proliferation of cells.

Initial inflammatory phase- This involves activating platelets and releasing cytokines and growth factors, which define characteristics.

Remodeling phase- The collagen is produced and organised, giving rise to the mature scar (Ibrahim *et al*.,

2018); Goldberg and Diegelmann, 2017).
Several factors can impede the wound healing process, such as infections, pre-existing medical conditions like diabetes or heart issues, certain medications, including steroids, and aging. Essentially, two types of signalling mechanisms exist within inflammation, those that initiate and sustain it and those that bring it to an end. These messages' asymmetries can damage tissues and cells and, due to the improper functioning of the whole process, might result in persistent inflammation

Table 4. Important antimicrobial activities of marine compounds reported in the literature

Marine Compound	Source	Mode of Action	Findings	Reference
Zinc oxide	Zincite, a mineral resource, can be used to create natural zinc oxide. Furthermore, it is synthesized.	Antimicrobial and antiinflammatory effects can be obtained by zinc oxide. It reduces sebum production, prevents the development of germs that cause acne (such Propionibacterium acnes), and reduces inflammation brought on by acne lesions.	It has a little dehydrating effect that aids in absorbing extra oil and clearing pores.	(Abendrot and Kalinowska-Li, 2018)
Alginate	Produced by a number of different brown seaweed species, including Laminaria and Ascophyllum.	It helps to absorb excess oil from the skin and regulates sebum production. Additionally, it has antiinflammatory properties that reduce acne-related redness and inflammation.	Alginate helps gently exfoliate dead cells from the skin, which can help with skin cleanliness.	(Abd-Allah *et al.,* 2020)
Niacinamide	Vitamin B3 comes in the form of niacinamide, which can be produced artificially or obtained naturally from foods like fish.	It reduces inflammation, regulates sebum production, and strengthens the skin's protective barrier.	Niacinamide also aids in the reduction of post-inflammatory hyperpigmentation (PIH), a condition frequently associated with acne, and has antibacterial properties against germs that cause acne.	(Madaan *et al.,* 2021)
Sea whip extract	Produced by Pseudopterogorgiaelisabethae, a type of Caribbean gorgonian coral.	It calming and antiinflammatory properties. It reduces redness and soothes inflammation brought on by acne.	Promotes a healthy complexion by reducing excessive sebum production.	(Draelos, 2011)
Chitosan	Obtained from crustacean shells, such as those of crabs, prawns and lobsters.	Antimicrobial and wound-healing capabilities are both found in chitosan. It aids in reducing acne-related inflammation and preventing acne-causing bacteria from growing.	Chitosan promotes skin regeneration and can speed up the recovery of acne lesions.	(Abd-Allah *et al.,* 2020)
Fucoidan	Brown seaweeds like Sargassum and Fucusvesiculosus.	It has antiinflammatory and antibacterial effects Both inflammation and the development of acne-causing bacteria are inhibited.	Fucoidan supports a healthy skin barrier and regulates sebum production.	(Zheng *et al.,* 2023)
Marine peptides	Produced by a variety of marine creatures, including sponges, fish, and algae.	Marine peptides have antibacterial qualities that work to kill acne-causing bacteria and reduce acne inflammation. Additionally, they can speed up wound healing and minimize acne scarring.	Marine peptides have the ability to improve skin moisture and improve general skin health.	(Fonseca *et al.*, 2023)
Marine enzymes	Obtained from marine sources, such as papaya (papain) & pineapple (bromelain).	They aid in unclogging pores, removing dead skin cells, and reducing acne-related irritation.	These enzymes may be helpful to reduce acne-related PIH.	(Vladkova *et al.,* 2022)

and, in more extreme circumstances, even death (Goldberg and Diegelmann, 2017). The more persistent inflammatory conditions of the skin, which include seborrheic dermatitis, eczema, atopic dermatitis, rosacea, and psoriasis, can manifest in a number of ways, including recurrent rashes accompanied by itching & redness of the skin (Demidova-Rice *et al.,* (2012).

In folk medicine, sea cucumbers, especially Stichopushermanni, sometimes known as "gamatemas," have been historically used to treat a variety of ailments, notably the healing of wounds. Another compound sourced from marine environments known for its wound-healing attributes is fucoidan (Khotimchenko, 2018), a sulphated, fucose-rich polysaccharide primarily discovered in the matrix of brown algae. The part cutaneous inflammation causes many illnesses, including cancer and discoid lupus erythematosus (DLE), as well as aging of the skin that is evident. It highlights how crucial it is to manage inflammation by using antioxidants, cosmeceuticals that reduce inflammation, and a diet high in antioxidant and antinflammatory foods. Microbiological, immunological, and toxic substances trigger the inflammatory response by triggering mediators such as prostaglandins, leukotrienes, Nitric Oxide (NO),Tumor Necrosis Factor-alpha (TNF-α), and interleukins. After that, the article explores methods for reducing the overproduction of pro-inflammatory eicosanoids, specifically arachidonic acid, and addresses problems with traditional therapies such as corticosteroids and nonsteroidal antiinflammatory medications (NSAIDs) (Ganceviciene *et al*., 2012; Yuan *et al*., 2023). The possible role that sea cucumbers—in particular, *Stichopus hermanni*—may have in the healing of wounds comes into light. Based on sustained release qualities, sea cucumber extracts have been shown in studies to speed up wound contraction rates and improve the efficacy of hydrogel wound dressings (Ming, 2001).

The antiinflammatory properties of sea cucumbers are also discussed in the article, with substances such as saponins being credited for their effectiveness. The fucoidan is a polysaccharide generated from marine algae that can heal wounds. Fucoidan is present in brown algae (Mou *et al*., 2018). Faster wound contraction is facilitated by the antiinflammatory and angiogenic properties of low molecular weight fucoidans (LMF). Collagen deposition is increased, tissue remodelling is accelerated, and antioxidant activity is demonstrated by LMF therapy, possibly via sulphate groups. It emphasizes how growth factors such as Vascular Endothelial Growth Factor (VEGF) and Transforming Growth Factor-beta (TGF-β) are involved in wound regeneration and how LMF treatment boosts their expression, which lends further credence to the substance's ability to heal wounds (Savari *et al*., 2019).

Marine sources derived cosmeceutical ingredients

The majority of marine resources can potentially be transformed into precious cosmeceutical chemicals by the marine bioprocess sector. Modern bioprocessing technologies have been created through separation to extract bioactive components from food products obtained from marine sources that can be utilised as cosmeceuticals. The transformation processes responsible for producing these compounds with functional qualities, for instance, enzyme-mediated hydrolysis activity, are enhanced by adjusting physicochemical variables like pH and temperature. Therefore, the ultrafiltration membrane method is employed to obtain an effective recovery while obtaining functional bioactive substances with the appropriate functional characteristics and molecular size (Resende *et al*., 2022). Numerous marine organisms contain a variety of compounds with fascinating properties that are used by the cosmetics industry. The ones that have already undergone commercialization are included in Table 5 (Boden, 2019).

Cosmeceuticals from marine origin

Consumers' growing interest in natural cosmetics has led to a rush to mine nature's rich supply of biologically active substances for use in cosmetics (Shaikh, 2022). As more and more customers seek goods made from natural sources, the cosmetics sector is releasing more and more products that contain marine-based extracts or components. The cosmetics sector increasingly focuses on research and development (R&D) to create products using compounds or extracts from natural sources. This shift aligns with a worldwide preference for items seen as beneficial to health, environmentally responsible, and eco-friendly (Siahaan *et al*., 2017). Due to their numerous benefits compared to synthetic alternatives, consumers are increasingly seeking cosmetic products that utilize innovative bioactive compounds from natural sources. While marine resources are now recognized as a rich reservoir of varied compounds with diverse biological properties suitable for cosmeceuticals, plant-based ingredients have long been and remain a staple in natural cosmetics. The extensive biodiversity in marine settings offers a wealth of chemical diversity with potential applications across pharmaceuticals, cosmeceuticals, molecular research, fine chemicals, and agrochemicals. Further research efforts are needed to fully grasp the vast potential of the marine environment, especially considering the numerous undiscovered marine species. Over time, marine organisms have developed various biochemical and physiological mechanisms for purposes like reproduction, communication, and defence against threats such as infections and predators. Given their beneficial properties like antioxidant, antiinflammatory, anti-allergic, antiaging, and UV protection, many of these compounds hold significant promise as cosmeceuticals

Table 5. Marketed product of marine origin for dermatological disorders

S. No.	Product	Ingredient	Source	Cosmetic Benefits	Company Website
1	Eleana	Marine collagen	Marine sponge	Reduces the wrinkles' visibility and protects the skin from free radical damage and irritation.	www.klinipharm.com/
2	Rose Plus marine collagen complex	Marine collagen	Marine collagen	Increases collagen and elastin production, reducing fine lines and creating smooth, velvety skin.	www.the organic pharmacy.com/
3.	SalmonCollagen	Marine collagen	Salmon skin	Profound penetration enhances the state of the skin from the inside out.	www.finncanada.com/
4.	Eclae	Carotenoids	Marine Phytoplankton (Dunaliella salina)	Produces a substantial amount of carotenoids and enhances the effects of anti-aging.	www.eclae.com/en/
5.	Abyssine	Exopolysaccharides	Alter monas ferment extract	Recognising and minimising irritation caused by skin sensitivity	www.unipex.com/
6.	Refirmar	Protein mixture	Pseudoalteromonas sp.	Moisturising, antiwrinkle, and reducing expression lines.	https,//bioalvo.com/
7	Sea Code	Glycoproteins	Pseudoalteromonas sp.	Protein maintenance in cells.	https,//lipotec.com
8	Resilience	Tricyclic diterpene glycoside	Pseudopterogorgia Elisabethae	Analgesic and antiinflammatory medication used to treat pain brought on by sunburn.	https,//esteelauder.es
9	Alguronic	Alguronic acid	Marine microalgae	Enhances the firmness and general health of the skin. reduces the visibility of tiny lines.	www.algenist.com/
10	Dermochlorella DG	Oligopeptides	Marine microalga (Chlorella sp.)	Boosts the firmness and tone of the skin and removes vascular defects.	www.codif-reserche-etnature.com/
11	Collagen Moisturizer	Marine collagen	Fish skin	Provides tissues with resilience and stops wrinkles from forming.	www.seanergy.es/
12	Hydrolysed Fish Collagen	Hydrolysed Fish Collagen	Fish skin	Encourages strong, healthy joints, hair, skin, and nails.	www.kenneyandross.com/

or marine-based cosmeceuticals (Harari, 2012).

Discovering new marine natural products often involves collecting specimens, which challenges their sustainability and reproducibility. Issues related to consistency arise due to environmental changes and shifts in the biochemical interactions within the target organisms' communities. Additionally, the substantial biomass often needed for drug discovery raises sustainability concerns. Furthermore, variations in the chemical composition of the same species across seasons or locations might mean the desired metabolite isn't consistently present. However, modern methods for raising marine invertebrates in aquaculture may provide a way around these two problems since they allow for the continuous production of animal biomass in the presence of uniform environmental circumstances (Romano *et al*., 2022).

Macroalgae-derived compounds

Generally speaking, cosmeceuticals—marine brown and red algae—are used in cosmetic goods (Jesumani *et al*., 2019). Seaweeds, or macroalgae, have long been used to manufacture phycocolloids such as alginates, carrageenan, and agar. Furthermore, some brown and red macroalgae varieties are utilised in cosmetics because they contain many physiologically active substances, vitamins, minerals, amino acids, carbohydrates, and lipids (Rahman, 2020). The macroalgae such as *Ulva lectica, Ascophyllum nodosum,* Laminaria species like *L. longicruris, L. saccharina,* and *L. digitata,* along with *Alaria esculenta, Chondrus crispus, Mastocarpus stellatus,* and various Porphyra species are commonly incorporated into cosmetic products. These algae naturally produce diverse chemical compounds as a defence against environmental stresses. Many of these compounds serve as pigments in cosmetics and are also recognized as cosmeceuticals, offering skincare benefits like protection against UV rays, oxidative damage, and signs of aging. Given their distinct properties, the cosmetic industry has utilized these functional components from macroalgae for years in roles such as moisturizers, skin conditioners, and agents to control product thickness (Ariede *et al*., 2017). Agar and carrageenan, two of its main products, have been employed in cosmetics and marine cosmetics as gelling, thickening, and stabilizing agents. About 59% of all macroalgae grown worldwide are brown algae, with red algae making up 40% and green algae less than 1% (CHA *et al*. 2011). Large-scale seaside cultivation of macroalgae is possible, and by adjusting the culture conditions, it is possible to regulate the production of the bioactive chemicals produced by the algae, including proteins, polyphenols, and pigments.

The over-production of cutaneous progeria, brought on by cellular senescence and increasing telomere degradation, was effectively reduced by a lipophilic extract of the brown alga *Alaria esculenta* (Christaki *et al*., 2013). It investigated how phlorotannin's from brown algae, namely EC, inhibit human cell lines' MMPs. At low concentrations, it was discovered that phenol tannins in EC selectively inhibited MMP-2 and MMP-9 activities and efficiently inhibited the activity of bacterial collagenase-1. Similar to the positive control drug doxycycline, the inhibitory effects were also observed in human dermal fibroblasts and HT1080 cells. Crucially, EC extract showed MMP inhibition without having harmful effects, suggesting that it could be used as a safe therapeutic MMP inhibitor for diseases such as wrinkle formation, arthritis, metastasis, and chronic inflammation (Kim *et al*., 2006).

Castillo *et al.* extracted bioactive chemicals from five Adriatic Sea algae using two different extraction procedures (ultrasound-assisted and matrix solid-phase dispersion), with ethanol/water being the most effective. Total phenolic content ranged from 0.2 to 38 mg GAE/g, and antioxidant activity varied with IC50 values between 44 and 11,040 mg/L. Liquid chromatography-tandem mass spectrometry identified abundant hydroxybenzoic acid derivatives, particularly in Gongolaria Barbata (up to 500 mg/kg).this shows that potential of these algae as a rich source of phenolic compounds (Castillo *et al*., 2023). The methanol extract of the red marine algae Corallina pilulifera (CPM) has been shown in vitro to be able to inhibit UV-induced oxidative stress as well as the expression of MMP2 and MMP9 in human dermal fibroblast (HDF) cells. Dermocea® by Gelyma is a commercially available product containing a mixture of algal extracts derived from the red algae Meristotheca diaresis and *Jania rubens*. This product is designed to enhance the production of keratin, glycosaminoglycans (GAGs), and collagen types I and III. (Ganesan *et al*., 2019).

Research suggests that marine brown and red algae offer significant potential as beneficial marine-derived cosmeceuticals, whether in pure compounds or extracts. Extracts from the green alga Chlamydocapsa sp., commonly referred as snow algae, are incorporated into skincare and hair care products to combat photoaging. It may also help prevent wrinkle formation from exposure to UV rays in cold, or dry conditions and protect against environmental factors that compromise skin barrier function (Ganesan *et al*., 2019; Chakraborty, 2023).

Marine invertebrate-derived compounds

Marine invertebrate-derived compounds are bioactive substances extracted from marine invertebrates, such as sponges and coral-derived compounds, as discussed below. These compounds have been found to have potential applications in various fields, such as cosmeceutical and drug discovery.

Marine sponge-derived compounds

Generally, some of the isolated bioactive secondary metabolites produced by marine invertebrates, particularly marine sponges, are thought to be produced by functional groups of enzymes derived from the associated microorganisms. When analysing the secondary metabolites produced by marine invertebrates, it is important to consider the relationship between these organisms and phytoplankton (Kennedy *et al*. 2009). These microbes are renewable sources of many natural compounds, which makes them potentially highly essential for new medicines and cosmeceuticals. Marine sponges are considered repositories of marine microbial variety, which may open up new possibilities for marine biotechnology. This is demonstrated by the fact that a large number of metabolites derived from sponges have properties in common with natural chemicals produced by bacteria and fungi, or they fall into the same family of substances (Wang *et al*., 2022). Microbes commonly reside within the mesophyll of sponges, and some studies have indicated that specific compounds initially identified from marine sponge extracts are created by microorganisms associated with these sponges. Furthermore, numerous natural substances isolated from marine sponges, including antibiotics, antifungals, and compounds with antipredator or antifouling properties, seem to be products generated by marine microbial activity (Petchiyammal *et al*., 2023). As bacteria give their hosts the byproducts of their metabolism, the sponges are able to acquire characteristics unique to bacteria, including autotrophy, nitrogen fixation, and nitrification. Moreover, these bacteria are capable of breaking down substances from metabolism that support the sponge skeleton and shield it from UV light (Patel *et al*., 2023).

However, to fight for space, marine sponges also produce enzymes. These enzymes can be employed as skin-whitening ingredients in a variety of cosmetic formulas, as well as to slow the growth of germs and fungus that could invade their host. Sponge metabolites are becoming more and more promising for use in cosmetics even though the cosmetics industry has only examined a small fraction of the bioactive substances identified in marine sponges (Rosner *et al*., 2023). For example, in the pigmented human melanoma cell line MM418, it was demonstrated that halistanol trisulphate, a C-29 steroidal detergent derived from the Indo-Pacific sponge Haliclona sp., inhibited the maturation of tyrosinase to a form linked with melanin formation (Townsend *et al*. 1992). The marine sponge Acanthella cavernosa was extracted in hexane, methanol, and ethanol. These extracts were tested for their antioxidant and antibacterial properties against P. acnes; only the ethanol extract showed these properties *in vitro*. So, a marine sponge may be used as a natural cosmeceutical made from marine extract to prevent acne (Yanti *et al*., 2015).

Coral-derived compounds

Coral powder is employed as a sustainable substance in various cosmetic products due to its textural, chemical, and physical properties and mineral content (Uppala 2015). In its composition, coral powder consists mainly of calcium carbonate and can contain approximately 74 other minerals, excluding heavy metals. When applied topically, coral powder offers skin mineral benefits, protection against UV rays, and properties that soften the skin and provide antioxidant, anti-aging, and antiacne effects. Additionally, it is used in creating formulations for deodorants and lipsticks (Uppala, 2015).

Additionally, certain coral secondary metabolites, such as diterpene glycosides like pseudopterosins, have been isolated from corals and have shown potential for use in cosmeceuticals. These compounds possess beneficial properties like antiinflammatory, antioxidant, and antiacne, making them essential ingredients for skincare formulations. Significant research has focused on the antiinflammatory effects of pseudopterosins, with particular attention given to pseudopterosin A. Their analgesic and antiinflammatory qualities have been observed to surpass those of current medications like indomethacin. The alteration of the arachidonic acid cascade by a pharmacological mechanism of action that is still unknown is the mechanism of action of pseudopterosins. It has been documented that pseudopseudopterosin A binds to G protein-coupled receptors to prevent phagosome formation and release intracellular calcium. Several other pseudopterosins have also been shown to exhibit remarkable antiinflammatory properties, and it is proposed that they prevent leukotriene production and human neutrophil degranulation (Bhattacharya, 2023).

Sea cucumber-derived compounds

The sea cucumbers are a great source of bioactive substances such as minerals, fatty acids, gelatine, vitamins, amino acids, phenols, chondroitin sulphate, saponins, carotenoids, and bioactive peptides. Wound healing, neuroprotective, anticancer, anticoagulant, antibacterial, and antioxidant properties are a few of the health benefits associated with sea cucumbers (Pangestuti and Arifin, 2018). Sea cucumber extracts are rich in vitamins such as A, B1 (thiamine), B2 (riboflavin), B3 (niacin), and various minerals including calcium, magnesium, iron, zinc, selenium, germanium, strontium, copper, and manganese. These components make them valuable ingredients for cosmeceutical applications. Sea cucumber extracts contain easily absorbed vitamins and minerals that replenish moisture and encourage the regeneration of damaged skin cells (Siahaan *et al*., 2017). The studies on the properties of sea cucumber extract are given in Table 6

Future perspectives

Even though there are now a few marine-related products in the market, the quantity of these products is still relatively small compared to the size of the ocean and the discoveries that yet lie ahead. Until 2012, just three categories of marine algal compounds—agar, carrageenan, and alginates—were used commercially. This suggests that a large number of marine compounds, particularly tiny molecules, can still be used to make cosmeceuticals. However, more work needs to be done on the products' isolation and characterisation to identify their pharmacophores molecular changes, assess their pharmacological qualities and safety aspects, enhance the product's quality, and, most importantly, more research and development funding.

Conclusion

The desire to appear younger and healthier has become a global concern as the baby-boomer generation

Table 6. Properties of the extracts of sea cucumber extract

Sea Cucumber extract	Properties	Reference
Stichopus japonicus	The ethyl acetate fraction of this extract effectively hindered melanin production by reducing the levels of essential proteins like tyrosinase, TRP-1, (tyrosinase-related protein-1) TRP-2, (tyrosinase-related protein-2) and the melanocyte-specific MITF (Microphthalmia-Associated Transcription Factor) isoform. exhibited minimal harm to human keratinocyte HaCaT cells and showed no negative effects in skin irritation tests on humans, reducing skin	(Yoon *et al.,* 2010)
Sanguisorba officinalis and Stichopus japonicus	It has skin-lightening properties, Stichopus japonicus reduced tyrosinase activity by 61.78%, whereas a combination of both reduced it by 59.14%. Suppresses melanin production in clone M-3 melanocytes showed non-irritating properties in ocular irritation	(Lee *et al.,* 2010)
Fucosylated chondroitin sulphates (FuCS)	It has anticancer, antioxidant, and angiotensin-converting enzyme inhibitory effects and promotes tissue repair.	(Yin *et al.* 2022; Guillerme *et al.,* 2017)

approaches senior age. People's awareness of the risks associated with using various chemicals in medications and cosmetics and the health advantages of compounds derived from natural resources has increased thanks to the population-informing power of social media and the efficient transmission of scientific data. Therefore, the utilisation of natural materials and eco-friendly procedures characterise this millennium. Marine biotechnology, also called "blue biotechnology," is gaining attraction as an alternative to "green technology" because it offers a wide range of naturally occurring compounds with unique biological and pharmacological qualities unavailable in terrestrial ecosystems. While the pharmaceutical industry has been at the forefront of tapping into the riches found in the ocean, the cosmetic industries are increasingly giving marine habitats more consideration. It is fascinating to note that these marine resources are underutilised despite some natural constraints. First and foremost, it is challenging to do more bioassays and development since relatively few molecules are separated from biological materials, often gathered from maritime habitats. The second factor is the production variations resulting from environmental changes that marine organisms are exposed to. Thus, a sustainable method for harvesting bioactive metabolites for use as active ingredients, excipients, and additives is needed, such as cultivating marine creatures under ideal conditions. This will help make microbiological biotechnology a viable option for producing many highly valued chemicals for cosmeceuticals.

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Conflict of interests

The authors declare that they have no conflict of interest.

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