SYSTEMATIC / NARRATIVE REVIEW ARTICLE

Oxybenzone in Sunscreen: A Comprehensive Ecotoxicological Review

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ABSTRACT

Introduction: Oxybenzone (benzophenone-3) is a widely used organic compound in sunscreens and other personal care products due to its ability to absorb ultraviolet (UV) radiation. It is effective in protecting the skin from harmful UV rays, thereby reducing the risk of skin cancer and photoaging. However, increasing concerns have emerged regarding the environmental impact of oxybenzone, particularly in marine ecosystems.

Materials and Methods: A comprehensive literature search was conducted using databases such as PubMed, Scopus, and Web of Science. Keywords included "oxybenzone," "sunscreen," "ecotoxicology," "marine organisms," and "environmental impact." Studies published from 2000 to 2023 were included to ensure a thorough understanding of the topic.

Results: Oxybenzone has been detected in various marine environments, with concentrations ranging from nanograms to micrograms per litre. Oxybenzone has been shown to cause bleaching in corals, impairing their ability to recover from stress. Research indicates that oxybenzone exposure can lead to endocrine disruption in fish, affecting reproductive success and behaviour. Oxybenzone has been found to be toxic to various invertebrates, including mollusks and crustaceans. Sub-lethal effects include impaired growth and development, as well as altered feeding behaviour. The data indicate a clear concentration-response relationship for oxybenzone toxicity across different species. Lower concentrations tend to produce sub-lethal effects, while higher concentrations can lead to mortality.

Discussion: The findings of this review highlight the significant ecotoxicological risks posed by oxybenzone in marine environments. The widespread use of oxybenzone in sunscreens, combined with its persistence in aquatic ecosystems, raises concerns about its long-term effects on marine biodiversity. A balanced approach that considers both human health and environmental sustainability is essential for the future of sunscreen formulations.

KEYWORDS:
Photosynthesis, UV filter, freshwater, marine water, coral reefs, oxybenzone, seed germination.

INTRODUCTION

Oxybenzone, because of its broad-spectrum ability to absorb photons in the ultraviolet (UV) part of the spectrum, including UVA and UVB, oxybenzone is a frequently used active component in sunblock and other Medicine and Personal Care Products (PPCPs).[1-3] Oxybenzone is also known as Benzophenone. It is a growing source of pollution in maritime areas, which is released by swimming as well as wastewater from homes, businesses, and boats and ships.[4] There have been reports of organic UV filters in drinking water, drinking water treatment facilities, drinking water treatment plants, bays, rivers, lakes, bathing waters, swimming pools, sediments, and biota/animals and plants. Because of the usage of sunscreen and PCP, studies have discovered measurable levels of organic UV filters in human urine, serum, and breast milk.[5-7] The coral reef is one kind of reef that can be found in the warm, shallow waters. Coral individuals are joined by connecting molecules, which allows them to live in groups for extended periods of time. Coral reefs provide a variety of sized spaces for the growth and residence of many species of fish, shrimp, shellfish, algae, and various other marine animals. In polyps, cryophyte is symbiotic. Through the process of photosynthesis, yellow algae are a type of algae plant that absorbs sunlight and supplies corals with nutrients. Sea levels will rise as a result of global warming, gravely endangering coral existence.

Apart from the detrimental effects of climate change on the marine ecosystem, oxybenzone has been found in sunscreen and other skin care products, as well as in freshwater and marine entertainment areas.[8] It is known to build up in aquatic species and transform into harmful compounds.[9] Studies have indicated that inorganic filters are superior to organic filters in terms of their ability to block UVA and UVB radiation. This is because inorganic sunscreens reflect UV light, whereas organic sunscreens absorb and convert it. Because oxybenzone is the most often used organic filter, Hawaii has placed restrictions on its use due to its harmful effects on the coral reefs.[10] High-energy visible light, infrared radiation, and ultraviolet radiation (UVR) are the three types of solar radiation. Sunscreens are primarily used to defend against ultraviolet radiation.[11]

UVR, which accounts for 6.8% of solar radiation overall, is separated into UVA (315-400 nm) and UVB (280-315 nm) wavelength groups.[12] Long-range, or UVA, waves are lower

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intensity waves that penetrate the dermis and promote ageing, tanning, and collagen degradation. On the other hand, UVB rays are short-wavelength, high-energy radiation that burns the epidermis. Though direct DNA damage and subsequent cancer formation are primarily caused by UVB radiation, reactive oxygen species produced by UVA photons can indirectly cause cancer. It is clearer in these cases that the organic UV filters in sunscreen constituted a significant environmental concern.[13] Therefore, the usage of inorganic UV filters such syctonemin and mycosporine-like amino acids (MAA) will not as much impact the marine ecosystem.

MATERIALS AND METHODS

An extensive and systemic literature review search about the topic was done in January 2024 using PubMed, Google Scholar, Research gate and Sci-finder databases. The database filtering of latest references articles and matching preferences were done through the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

Organic and Inorganic filters:
Sunscreens differ in their efficacy, which is mostly based on their ingredients. Sunscreens are primarily categorised based on the kind of UV filters (also known as active ingredients) that they contain; they can be physical (also known as mineral or non-soluble), chemical (commonly known as organic or soluble), or a mixture of the two.8 It has reportedly been used in more than 2000 skincare formulae from a variety of product categories, such as colour cosmetics, skin and hair care, and fragrances.[14] In polymers, it also acts as a stabiliser and an absorber of UV radiation. In 1990, oxybenzone was included in the Environmental Protection Agency's High Production Volume Challenge Program, which identifies chemicals produced or imported into the US at quantities greater than one million pounds per year.[15]

Conversely, chemical filters take in a narrow range of UV rays and use a chemical reaction to transform them into heat energy. To provide sufficient sun protection, several chemical filters must be mixed due to their limited absorption ranges.[11] Oxybenzone is the most often used chemical filter. However, the UVA rays that cause aging can only be blocked by oxybenzone. Physical sunscreens reflect UV light, whereas chemical filters absorb it. This is the main difference between chemical and physical sunscreens, other than composition. Benzophenones were originally employed as preservatives in industrial products such as paints, varnishes, and plastics to increase shelf life and decrease photodegradation.16 Benzophenones were also introduced to sunscreens in the 1950s; while there were initially six distinct benzophenones used as sunscreens, the four most commonly used agents in personal care products today are benzophenones-3, -4, -8, and -10. In a 2011 study on the frequency of known contact allergens in cosmetic and dermatological products, benzophenone-3 was detected in 68% of the 201 sunscreens analysed.[17] This means that the amount of benzophenone-3 found in US sunscreens is more than all other benzophenones combined.

Active Components of Sunscreen:
UV filters are the active ingredients of sunscreens and are classified as either soluble or non-soluble. Zinc oxide and titanium dioxide are examples of non-soluble filters, commonly referred to as mineral or physical filters, and are therefore categorised as physical sunscreens. On the other hand, soluble filters, often referred to as chemical or organic filters, are categorised as chemical sunscreens because they contain a variety of chemical compounds like octinoxate and oxybenzone. Aromatic chemicals such as oxybenzone and octinoxate, absorb UV radiation and release the energy as heat.

Inorganic UV filters:
In addition to sunscreens, oxybenzone and octinoxate are frequently found chemicals in personal care items like shampoo, lip balm, lotion, and insect repellent. Nevertheless, it is believed that oxybenzone and octinoxate are allergic, affect hormones in both humans and wildlife, and bleach coral. Indeed, in 2014, benzophenones were named contact allergen of the year, primarily due to the influence of oxybenzone, also known as benzophenone-3.[17] Because oxybenzone is a phototoxicant, its negative effects are amplified in bright light. Oxybenzone changed planulae from a motile to a distorted, sessile state, regardless of light or darkness. Planulae showed a rising rate of coral bleaching in response to rising oxybenzone concentrations.[4] Increases in oxybenzone concentrations are positively correlated with DNA-AP lesions, indicating that oxybenzone is a Geno toxicant to corals. Being a skeletal endocrine disruptor, oxybenzone caused the planula to ossify, encasing the entire structure in its own skeleton.

In the past ten years, sunscreens have been used to prevent photoaging, photosensitivity, skin cancer, and damage from free radicals in addition to their original purpose of protecting against erythema. Sunscreen is frequently used on big portions of the body. Large amounts of sunscreen are used since it is advised to apply them regularly and to reapply them after coming into contact with water. Sunscreens are occasionally included to common items like moisturisers and hair treatments; as a result, users often use them without realising it. Systemic absorption should be taken into account because sunscreen use is so common.

Environmental Impact:
Environmental effects are currently a hot topic. Recently, state legislation was approved in Hawaii to limit the use of oxybenzone and octinoxate containing personal care products, particularly in areas close to beaches. Prior research has indicated elevated levels of discernible active components in coastal waters.[18] Over the past few decades, as public knowledge of the dangers of UV radiation exposure on the skin has grown, so too has the usage of sunscreen cosmetic products, which has resulted in the introduction of novel chemical compounds into the marine environment.[14] Despite being the world's largest and fastest-growing tourism and recreation industries, sunscreen's potential chemical source to the coastal marine ecosystem has not been evaluated. Varying throughout the day, quantities of chemical UV filters included in sunscreen formulations, such as octinoxate and oxybenzone, have been found in nearshore seas.

Oxybenzone has been shown to be the most commonly discovered UV filter in the greatest amounts across water sources worldwide. There are various ways that organic filters get into the environment.[14] Urine absorbs them through the skin and excretes them, which gets into the plumbing.[4] The majority of the skin filter needs to be washed off with natural water sources or in a shower, with all the water used returning back into the water supply. The amount of applied dosage that was excreted in the urine was just about 4%. Furthermore, waste and industrial particulates found in factory discharge bring biological filters into the water supply system. In actuality, research indicates that oxybenzone concentrations in the drinking water supply are higher in metropolitan areas with commercial and industrial water flow than they are at recreational water sites. Organic filters are often found in the waste from manufacturing facilities, particularly those that make sunscreen and cosmetics. It is not shocking that these filters have been widely found in our water supplies given the rising usage of sunscreens and increased awareness of the value of photoprotection.

Impact on Coral reef:
The main factor for corals to go extinct is global warming. Seawater becomes more acidic due to the ocean's ability to absorb carbon dioxide from the atmosphere. As a result, the coral will be less able to convert their bones into calcareous, which will prevent them from growing and ultimately cause them to die. The primary cause of the coral bleaching is the sunscreen that people use worldwide. According to the study, coral reefs can become whiter when sunscreen is used, even in tiny amounts for skin protection. Indeed, oxybenzone has been found in freshwater and marine recreational areas in sunscreen as well as other skin care items. It builds up in aquatic species and transforms into harmful compounds.[10]

A tiny amount of sunscreen might cause a significant amount of coral mucus to leak out between 18 to 48 hours and totally whiten the coral within 96 hours, according to experiments conducted in a number of marine environments. It is not humanity's ultimate purpose, but rather the complete and enduring protection of coral reef resources.[9] A coral reef is an ecological resource in addition to a biological resource. Historically, coral and coral reefs were primarily employed for their biological and physical qualities, which made them unsustainable and inherently destructive. In fact, many cosmetics contain ingredients from animals and plants. The cream or shampoo we use may include plant extracts, such as lavender and tea tree oil, which will appear in many soaps and cosmetics.

Sustainable use of coral reefs:
For many tiny and medium-sized fish, coral reefs offer a decent habitat, cover, and breeding location because of their complex and varied topography. As a result, diverse dense fish groups up to thousands at times are frequently observed in coral reef areas, which constitute coral reef areas for fishing. We can create high-yield and stable-yield marine pastures without negatively affecting coral reef resources if we intentionally take use of the ecological features of coral reefs to provide fish and other marine organisms with habitats, shelters, and breeding places. We can also artificially breed valuable marine resources in coral reef areas and place marine organisms that love coral reefs in specific areas.[10]

Reef-building corals and the calcium carbonate bones left behind by other biological communities make up coral reefs.[9] Because of their strong physical characteristics, these reefs can withstand strong winds and waves and provide good protection for trees, coastal landforms, and artificial buildings along the reef edge. As a result, while developing coastal engineering projects, people can deliberately take use of the physical characteristics of coral reefs and include them into their plans for protecting against wind and waves. This not only efficiently prevents the occurrence of marine natural disasters but also lowers the cost of engineering. Knowledge of marine ecology and marine environmental preservation can be disseminated to coastal inhabitants and students in primary and secondary schools through the built coral reef nature reserve and its display hall. Concurrently, scientific investigations and trials concerning the revitalisation and advancement of impaired coral reef resources in specific regions can be conducted, together with technological and scientific collaboration and exchanges between local and international entities in this domain.

Effect on food chain:
Fish and animals have been investigated in relation to UV filters. It prevents rats from engaging in sexual behaviour and from reproducing. In zebrafish, octocrylene alters the way the liver and brain develop. Vitellogenin protein, a precursor to the embryo's yolk that is only present in females, was expressed by males exposed to high concentrations of oxybenzone in experiments conducted on Japanese rice fish (medaka) and rainbow trout. This resulted in decreased egg production, with noticeably less hatchings. Male fish that contain vitellogenin may have undergone feminization, which would have clear effects on reproduction. White fish, roaches, and perch observed in lakes in Switzerland have minimal but noticeable levels of UV filters. Cod liver in Norway has UV filters in it.[19] With 80% of the specimens identified, octocrylene was the most often encountered filter, followed by oxybenzone (50%). Octinoxate and oxybenzone were also present in white fish. Similar UV filters have been found in rainbow trout, white fish, chub, perch, and mussels in Spain. Although fish have modest concentrations, it is nevertheless important to take into account the ideas of biological magnification and the bioaccumulation.

The process by which substances gradually accumulate in organisms at higher quantities than in their surroundings is known as bioaccumulation. When Brausch and Rand looked at bioaccumulation, they discovered that fish had higher oxybenzone levels than water. The idea that chemicals grow more concentrated and harmful as one climbs the food chain is known as "biomagnification." Because lower species cannot eliminate or break down chemicals, an animal that consumes these lower-order organisms gets a higher dose of the chemical. This implies that eating seafood may have bad consequences for people, even if there haven't been any confirmed harmful effects on people as of yet.

Effect on humans:
Numerous adverse cutaneous reactions, such as contact and

photocontact dermatitis, contact and photocontact urticaria, and anaphylaxis, have been linked to oxybenzones. They have gained particular notoriety recently for their capacity to cause allergies and photoallergy. For the majority of patients, these allergens come from topical sunscreens and other cosmetics, but there are also reports of reactions that happen as a result of using industrial items.[20] Contact urticaria brought on by cosmetic chemicals that have elicited positive skin reactions after open, scratch, but most frequently, prick testing, in addition to immediate clinical symptoms. Certain IgE antibodies were occasionally found to be a basis for the diagnosis.[21] Eight years after the initial case of non-Y light-related contact dermatitis, photoallergic dermatitis caused by exposure to oxybenzone was first documented in 1980.

More cases of photoallergic contact dermatitis have been linked to oxybenzone than to any other UV filter. Studies done in the United States have shown that this chemical causes photoallergy, although there have been even more positive photopatch reactions in Europe. It's also crucial to remember that this chemical frequently causes problems because it's used in cosmetics that aren't intended to be sunscreens. Numerous extensive photopatch studies conducted in the US and numerous other countries have revealed that oxybenzone is also a major contributor to photoallergy in patients experiencing negative reactions to sunscreens.[22-24] In humans, oxybenzone has been associated with Hirschsprung's disease, used as a potential endocrine disruptor, and documented to cause contact and photocontact allergic reactions. It has been demonstrated that oxybenzone causes a range of harmful effects on fish and coral that extend from reef bleaching to fish death.[5] Last but not least, with the given the rise in skin cancer cases and the development of more potent sunscreen active ingredients like titanium dioxide and micronised zinc oxide, serious questions regarding the relative efficacy of oxybenzone-containing personal care products in preventing skin cancer need to be asked and contrasted with the possible harm to human health and the environment that could result from the buildup of this and other chemicals in the environment. Non-nano zinc oxide and non-nano titanium dioxide are UV resistant alternatives to oxybenzone that are recognised as "generally recognised as safe and effective" (GRASE), by the US Food and Drug Administration (FDA).[6]

Uses of oxybenzone:
In sunscreen preparations, oxybenzone is frequently employed as a short-wave (290-320 nm) ultraviolet light (UVB) and primarily short-wave UVA (320-340 nm) absorber at concentrations up to 6%. It is also used as a photo-stabiliser in personal care products, up to 0.5%, to reduce colour and odour changes. More than 2000 personal care formulas, including those for skin and hair care, colour cosmetics, and scents, have reportedly employed it. It also serves as a stabiliser and ultraviolet light absorber in plastics. In 1990, the Environmental Protection Agency's High Production Volume Challenge Program included oxybenzone to its list of approved chemicals. This tool finds ingredients that are produced or imported into the United States in more than a million pounds each year.[5]

Syctonemin and MAA as inorganic UV filters:
Mycosporine like amino acids:
Around 25% of the world's primary production is derived from cyanobacteria, which also predominate in large portions of the ocean and biological soil crusts. They must have light in order to perform photosynthesis, but they are also subjected to high UV radiation levels.

UVR-induced damage reduces photosynthetic rates, indicating that earlier estimates of the world's primary production may have been exaggerated.[25] Fundamentally, in cyanobacteria, MAAs are synthesised via a biosynthetic gene cluster (BGC) comprising at least three components.[26] MAAs have enormous biotechnological potential as the next wave of sunscreen ingredients. MAAs are tiny compounds that absorb ultraviolet light synthesised by cyanobacteria. Many marine animals also consume and accumulate these metabolites. Mycosporines and MAAs were found and given their names because they mediate light-induced fungal sporulation.

However, they also play a role in a variety of other biological processes, such as osmotic control, UV photoprotection of organisms and their embryos, and defence against oxidative stress. Additionally, their commercialization is a result of their capacity to prevent UV-induced skin damage in vivo.[27] MAAs have enormous biotechnological potential as the next wave of sunscreen ingredients. According to recent research, some of the chemicals included in commercial sunscreens, like benzophenone-3, can be harmful to corals.[28]

Syctonemin:
All taxa of extremophilic cyanobacteria are exclusively capable of producing the essential photoprotective agent scytonemin. It is a small, highly polar, lipid-soluble pigment molecule that ranges in hue from yellow-brown to dark red or mahogany. Cyanobacteria manufacture it as a component of their extracellular sheath.[29] Indolic and phenolic subunits combine to form the dimeric molecule scytonemin. This olefinic carbon atom connects the two subunits of scotylenemin. In general, there are two forms of scytonemin: reduced (red) and oxidised (green). Nonetheless, four unique scytonemin derivatives—dimethoxy, tetramethoxy, scytonin, and scytonemin-3a-imine from different cyanobacteria have also been reported. UV-A light greatly stimulates the manufacture of scytonemin in cyanobacteria.[29] Research indicates that UV-A radiation induced the expression of the gene cluster responsible for scytonemin biosynthesis, leading to the buildup of this naturally occurring sunscreen pigment outside of cells.[24,25] The *Chroococcidiopsis* sp. and Scytonema sp. of cyanobacteria were discovered to produce scytonemin when exposed to UV-A, oxidative stress, and temperature increases.

Solutions:
Applying sunscreen only to exposed areas, wearing swimwear, wide-brimmed hats, and sunglasses, and finding shade when outside are all examples of photoprotective clothing. Using sunscreen with inorganic filters (Syctonemin and MAA) and adhering to the aforementioned guidelines are two additional ways to shield oneself from UV rays. Apart from limiting the continuous discharge of UV filters into the

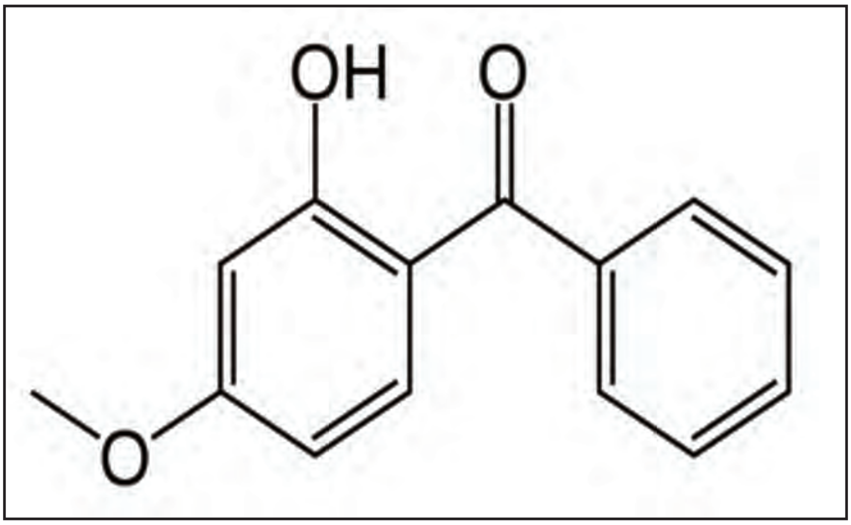

Fig. 1: Chemical Structure of Oxybenzone

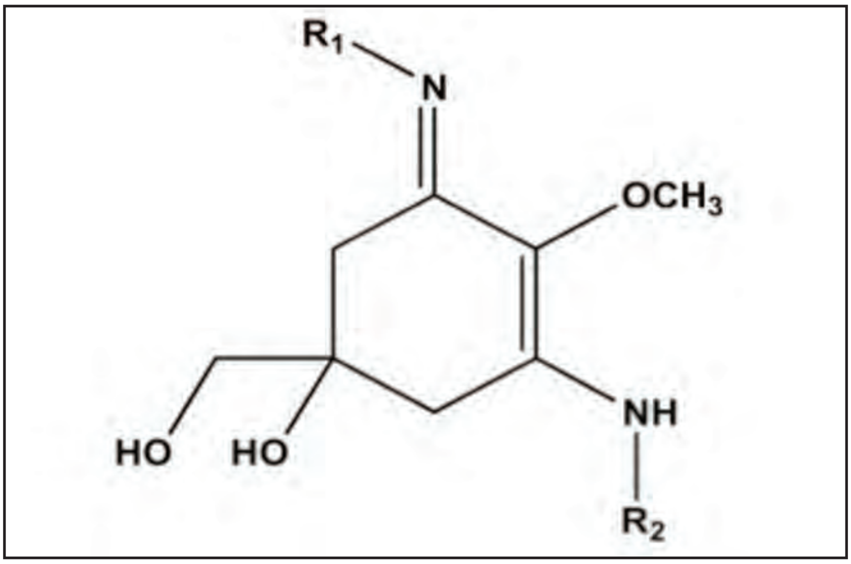

Fig. 2: General structure of MAA

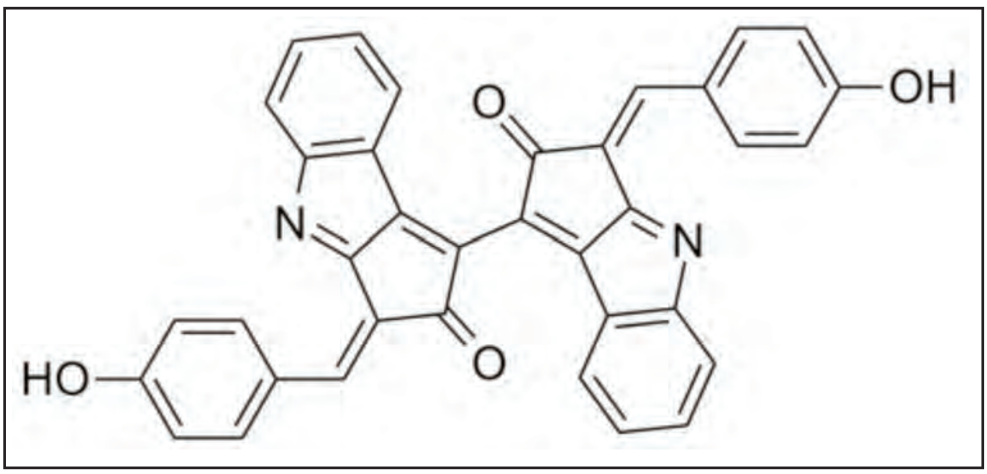

Fig. 3: Chemical structure of Syctonemin

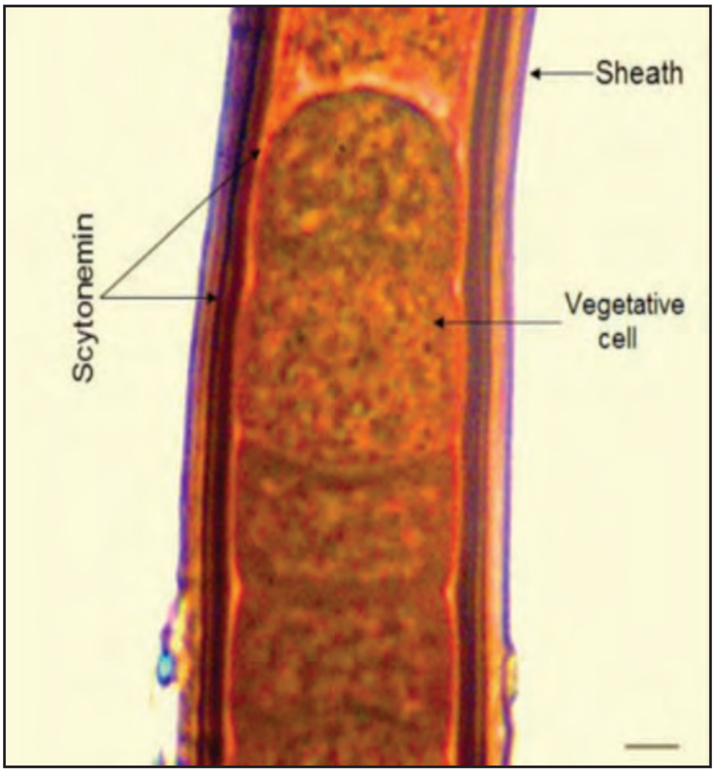

Fig. 4: Vegetative cells within a polysaccharide sheath containing the yellow-brown pigment scytonemin are seen in a filament of Lyngbya sp.

surroundings, methods to optimise their removal from the water resources have also been studied. Studies have been done on *Cyperus alternifolius* L., a widespread wetland plant that absorbs oxybenzone through its roots and builds up the toxin in its tissues. Finally, the plant converts oxybenzone into chemical conjugates that are less toxic. This method was considered as a potential way to remove oxybenzone from the environment; however, it was noted that these plants would need to be removed before they could begin to decompose naturally.[30,31]

CONCLUSION

Photoprotection is essential due to the established effects of UV radiation on erythema, photoaging, and the onset of skin cancer. Nevertheless, we also need to consider how our actions affect the environment. Numerous water sources have been found to include UV filters, which are very challenging to remove using conventional wastewater treatment plant procedures. One might assume that concentrations in our water sources will continue to rise if organic filters are used continuously. Although the impact on coral reefs is undoubtedly complex, UV filters may become increasingly crucial to bleaching at higher concentrations. Moreover, rising ocean concentrations will highlight bioaccumulation and biomagnification, which could have unfavourable effects on humans in the long run. Given the mounting evidence of the detrimental effects of organic UV filters on our environment, it is evident that we should investigate new techniques for water filtration and alternate photoprotection strategies. While research on the environmental effects of inorganic filters is ongoing, physical blockers are now advised as a substitute for photoprotection. The public should be made aware of the significance of photoprotection, which includes seeking shade, wearing photoprotective clothing and swimwear when outdoors, and applying the proper sunscreen to sun-exposed areas. This should not be compromised by worries about the environmental effects of organic UV filters. This would enable us to safeguard both the environment and our skin from the damaging effects of sunshine. Worldwide, oxybenzone is present in human urine, serum, and breast milk in addition to being present in water, soil, sediments, sludge, and biota. It is not as good as avobenzone as a sunscreen active at preventing UVA ray exposure. This substance is a known contact and photo contact allergen that can cause contact urticaria and, to a lesser extent, contact-mediated anaphylaxis in people. It has also been connected to Hirschsprung's illness. In the environment, oxybenzone prevents fish and coral from reproducing by poisoning embryos, feminising male fish, bleaching coral, and/or killing them. In summary, industry and regulatory bodies should evaluate the possible harm to human health and the environment that may result from the build-up of this and other chemicals in the ecosystem before developing and introducing novel, efficacious personal care products.

CONFLICT OF INTEREST

Authors declare there is no conflict of interest.

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REFERENCES

1. Zhong X, Zhang ZS, Li SH, Li YM, Liu BB, Li QM, et al. Inhibition of photosynthesis in cucumber leaves by oxybenzone. Photosynthetica 2020; 58(1): 1-8.
2. Emonet S, Pasche-Koo F, Perin-Minisini MJ, Hauser C. Anaphylaxis to oxybenzone, a frequent constituent of sunscreens. J Allergy Clin Immunol 2001; 107(3): 556-7.
3. Kasichayanula S, House JD, Wang T, Gu X. Percutaneous characterization of the insect repellent DEET and the sunscreen oxybenzone from topical skin application. Toxicol Appl Pharmacol 2007; 223(2): 187-94.
4. Kryczyk-Poprawa A, Sánchez-Hidalgo A, Baran W, Adamek E, Sułkowska-Ziaja K, Kała K, Muszyńska B, Opoka W. The Toxicological Impact of the Ultraviolet Filter Oxybenzone on Antioxidant Profiles in In Vitro Cultures of Lentinula edodes. Toxics 2025; 13(3): 145.
5. DiNardo JC, Downs CA. Dermatological and environmental toxicological impact of the sunscreen ingredient oxybenzone/benzophenone-3. J Cosmet Dermatol 2018; 17(1): 15-9.
6. Mao JF, Li W, Ong CN, He Y, Jong MC, Gin KY. Assessment of human exposure to benzophenone-type UV filters: A review. Environ Int 2022; 167: 107405.
7. Ruszkiewicz JA, Pinkas A, Ferrer B, Peres TV, Tsatsakis A, Aschner M. Neurotoxic effect of active ingredients in sunscreen products, a contemporary review. Toxicol Rep 2017; 4: 245-59.
8. Zengin G, Cetiz MV, Abul N, Gulcin I, Caprioli G, Piatti D, et al. Establishing a link between the chemical composition and biological activities of Gladiolus italicus Mill. from the Turkish flora utilizing in vitro, in silico and network pharmacological methodologies. Toxicology Mechanisms and Methods. 2025; 12;35(2):146-66.
9. Zhu X, Zhao L, Jiang H, Huang Y, Wang J, Sha L, et al. Production of short-chain n-fatty acids in coral reefs in the southern South China Sea since the Late Miocene. Palaeogeogr Palaeoclimatol Palaeoecol 2022; 592: 110898.
10. Miao Z. Damage of Oxybenzone in Sunscreen to Coral Reefs. Int J Biol Life Sci. 2022;1(1):17-9.
11. Siller A, Blaszak SC, Lazar M, Olasz Harken E. Update about the effects of the sunscreen ingredients oxybenzone and octinoxate on humans and the environment. Plast Surg Nurs 2018; 38(4): 158-61.
12. Smith CJ, Livingston SD, Doolittle DJ. An international literature survey of "IARC Group I carcinogens" reported in mainstream cigarette smoke. Food Chem Toxicol 1997; 35(10-11): 1107-30.
13. Uddin MM, Chowdhury MS, Hossain MA, Ahsan A, Hossain MT, Barik A, Hossen MA, Amin MF, Abir R, Alam MS, Rahman MH. Molecular screening and dynamics simulation reveal potential phytocompounds in Swertia chirayita targeting the UspA1 protein of Moraxella catarrhalis for COPD therapy. PloS one 2025; 20(2): e0316275.
14. Blitz JB, Norton SA. Possible environmental effects of sunscreen run-off. J Am Acad Dermatol 2008; 59(5): 898.
15. Siller A, Blaszak SC, Lazar M, Olasz Harken E. Update about the effects of the sunscreen ingredients oxybenzone and octinoxate on humans and the environment. Plast Surg Nurs 2018; 38(4): 158-61.
16. Knox JM, Guin J, Cockerell EG. Benzophenones; ultraviolet light absorbing agents. J Invest Dermatol 1957; 29(6): 435-44.
17. Ramsay DL, Cohen HJ, Baer RL. Allergic reaction to benzophenone: simultaneous occurrence of urticarial and contact sensitivities. Arch Dermatol 1972; 105(6): 906-8.
18. Schneider SL, Lim HW. Review of environmental effects of oxybenzone and other sunscreen active ingredients. J Am Acad Dermatol 2019; 80(1): 266-71.
19. Heurung AR, Raju SI, Warshaw EM. Benzophenones. Dermatitis 2014; 25(1): 3-10.
20. Verhulst L, Goossens A. Cosmetic components causing contact urticaria: a review and update. Contact Dermatitis 2016; 75(6): 333-44.
21. Buhry JN. Photo allergies from benzophenones and beta carotene in sunscreens. Contact Dermatitis 1980; 6(3): 211-39.
22. Cardoso JC, Canelas MM, Gonçalo M, Figueiredo A. Photopatch testing with an extended series of photoallergens: a 5-year study. Contact Dermatitis 2009; 60(6): 325-9.
23. Szczurko C, Dompmartin A, Michel M, Moreau A, Leroy D. Photocontact allergy to oxybenzone: ten years of experience. Photodermatol Photoimmunol Photomed 1994; 10(4): 144-7.
24. Shanmugam R, Arthi B, Pragya P, Girigoswami A, Koyeli G, Pemula G, Senthilkumar N, Arumugam VA. A Comprehensive Assessment of the Antioxidant Capacity of Varied Bacopa Monnieri Extracts and Its Toxicity on Early Life Stages of Zebrafish Embryos. Natural Product Communications 2025; 20(3): 1934578X251327815.
25. Balskus EP, Walsh CT. The genetic and molecular basis for sunscreen biosynthesis in cyanobacteria. Science 2010; 329(5999): 1653-6.
26. De la Coba F, Aguilera J, Figueroa FL, de Gálvez MV, Herrera E. Prevention of the ultraviolet effects on clinical and histopathological changes, as well as the heat shock protein-70 expression in mouse skin by topical application of algal UV-absorbing compounds. J Dermatol Sci 2009; 55(3): 161-9.
27. Danovaro R, Bongiorni L, Corinaldesi C, Giovannelli D, Damiani E, Astolfi P, et al. Sunscreens cause coral bleaching by promoting viral infections. Environ Health Perspect 2008; 116(4): 441-7.
28. Rastogi RP, Sonani RR, Madamwar D. Cyanobacterial sunscreen scytonemin: role in photoprotection and biomedical research. Appl Biochem Biotechnol 2015; 176(6): 1551-63.
29. Sorrels CM, Proteau PJ, Gerwick WH. Organization, evolution, and expression analysis of the biosynthetic gene cluster for scytonemin, a cyanobacterial UV-absorbing pigment. Appl Environ Microbiol 2009; 75(14): 4861-9.
30. van Iterson M, 't Hoen PA, Pedotti P, Hooiveld GJ, den Dunnen JT, van Ommen GJ, et al. Relative power and sample size analysis on gene expression profiling data. BMC Genomics 2009; 10(1): 439.
31. Chen F, Huber C, Schröder P. Fate of the sunscreen compound oxybenzone in Cyperus alternifolius based hydroponic culture: Uptake, biotransformation and phytotoxicity. Chemosphere 2017; 182: 638-46.