National Journal of Advanced Research
www.multidisciplinaryarticle.in
ISSN: 2455-216X
Received: 13-07-2024, Accepted: 04-07-2024, Published: 27-07-2024
Volume 10, Issue 2, 2024, Page No. 16-21

Elegance in Ecology: Unveiling Mycosporine-like Amino Acids (MAAs) Allocation, Applications, Patterns, and Implications

Prathima R[1], Avipsa Hazra[1], Nandini G[2], Kanthesh M Basalingappa[1*]
[1] Division of Molecular Biology, School of Life Sciences, JSS Academy of Higher Education and Research, Mysuru, Karnataka, India
[2] Department of Studies in Zoology, Karnataka State Open University, Mysore, Karnataka, India

Abstract
The ecological presence of Mycosporine-like Amino Acids (MAAs) represents a captivating and essential aspect of the natural world's response to the ever-present threat of ultraviolet (UV) radiation. These remarkable compounds, initially discovered in the 1960s, have proven to be widespread, inhabiting various organisms across a spectrum of ecosystems. Their primary role as natural sunscreens is nothing short of vital; they serve as guardians, shielding the delicate cellular structures and precious DNA of countless species from the potentially devastating effects of UV-induced damage. However, what makes MAAs truly intriguing is their dynamic distribution and allocation across different environmental zones. For instance, in regions subjected to intense UV radiation, such as the unforgiving Antarctic zone or the contrasting temperate and tropical zones, organisms have evolved to adapt and allocate MAAs strategically. This allocation pattern reflects the remarkable adaptations that nature has developed to confront the diverse challenges posed by varying UV conditions. Moreover, the potential applications of MAAs extend beyond the confines of the natural world. These compounds hold immense promise in sunscreen products for human protection, safeguarding aquatic ecosystems from the harsh effects of UV radiation, and advancing biotechnological solutions. As we explore the patterns and implications of MAAs in this review, we gain deeper insights into their ecological significance and their potential to revolutionize industrial contexts, all within the intriguing framework of Elegance in Ecology: Unveiling Mycosporine-like Amino Acids (MAAs) Allocation, Applications, Patterns, and Implications.

Keywords: Ecology, mycosporine-like amino acids (MAAs), ultraviolet (UV) radiation

Introduction

Amongst the ongoing debates surrounding global environmental issues, such as global warming and alterations in ultraviolet (UV) radiation levels, there emerges a growing concern within the scientific community about the ecological implications of Mycosporine-Like Amino Acids (MAAs). These unique compounds, are involved in both protecting and nourishing organisms in response to changing radiation levels, have garnered significant attention from phycologists and ecologists alike. In recent decades, the discourse has increasingly centered on the intricate interplay between global climate shifts and the penetration of life-threatening ultraviolet (UV) rays, alongside life-preserving photosynthetically active radiation (PAR). Furthermore, as the stratospheric ozone layer continues to deteriorate due to anthropogenic activities and the diminishing presence of aerosols and cloud cover, a looming concern arises: the projected escalation of ultraviolet radiation (UVR) that reach the Earth's crust. The ultraviolet radiations have physiological impacts, affecting organisms genetically and posing photosynthetic harm to a wide spectrum of life forms, ranging from minute unicellular organisms to multicellular ones. The consequences of the increasing influx of UVR on various ecosystems are contingent upon this variability, contributing to the unpredictability of its ecological implications. UV-B radiation primarily affects the uppermost layer of the skin, known as the epidermis, as it does not penetrate into the deeper dermal layers [1]. This exposure at the epidermal level can lead to cytotoxic damage. In contrast, UV-A rays possess the ability to penetrate the epidermis and reach the dermis, resulting in various signs of aging, such as wrinkles, dryness, roughness, changes in pigmentation, and other age-related alterations. Additionally, exposure to UV- A radiation can generate reactive oxygen species that damage DNA. Interestingly, even though UV- B radiation has a milder impact on the skin, it exerts a more pronounced phototoxic effect in comparison to UV-A. In aquatic ecosystems, UV-B radiations can have consequences such as mutagenesis, the persistent impairment of vital physiological processes like acute physiological distress, photosynthesis, and ultimately leading to the decline of algae [2]. Conversely, macroalgae residing in intertidal and shallow water environments face the challenge of managing elevated levels of radiation, necessitating effective protective mechanisms or strategies to avoid potential harm [3]. A notable category of natural compounds, the mycosporine-like amino acids (MAAs), have attracted significant attention in this context [4]. These nitrogenous secondary metabolites are synthesized by a variety of phototrophic species, including blue-green algae, macroalgae, and dinoflagellates found in both terrestrial and aquatic habitats, primarily to provide photoprotection.

MAAs are characterized by their modest molecular weight (around 400 Da) and exhibit peak absorption in the 310-360 nm range, featuring substantial molar attenuation coefficients (ε) ranging from 28,100 to 50,000 M-1 cm-1. Their distinctive chromophore consists of a cyclohexenimine or cyclohexenone ring, which is linked to an amino group, amino acid, or amino alcohol nitrogen. This base structural foundation can form two distinct chemical categories of MAAs: one includes mycosporinetaurine, mycosporine-glycine, usujirene, palythine, asterina-330, Porphyra-334, and shinorine. However, the challenge for humans lies in our inability to naturally produce a sufficient quantity of these photo-protective and photo-absorbing substances to effectively shield our skin and bodies from the harmful impacts of UV rays [5].

Recent discoveries have unveiled an unexpected aspect of mammalian pigment melanin, traditionally known for its role in providing protection against skin cancer. It has come to light that melanin also plays an unforeseen role in the production of photoproducts from DNA, when exposed to sunlight for hours [6]. Furthermore, contemporary consumer preferences, rooted with environmental awareness, indicate a growing inclination toward natural products that are trustworthy for long term usage and devoid of any unknown deleterious effects. MAAs emerge as a suitable solution to meet these demands, having evolved naturally to address these issues. This study explores how Mycosporine- like amino acids (MAAs) are distributed within the ecosystems, their allocation patterns with respect to UV radiation exposure, and the ecological significance of these compounds. It highlights the importance of MAAs in protecting and nourishing different organisms in the face of increasing UV exposure due to environmental changes.

Ecological Allocations

The allocation of MAAs has consistently exhibited a broad biogeographical range. Among the over 150 species of cultured microalgae from water bodies, representing 12 different types and totalling 206 strains, a significant proportion were found to likely possess substantial quantities of MAAs. Within this group, 26 species were sourced from tropical regions, 173 belong to the subtropical and temperate regions, and seven from Antarctic regions. It was observed that strains belonging to dinoflagellates, prymnesiophytes, cryptomonads, and raphidophytes consistently exhibited higher quantitative concentrations of MAAs compared to those from euglenophytes, diatoms, eustigmatophytes, prasinophytes, chrysophytes, cyanophytes, chlorophytes, rhodophytes, and other algal groups [7]. However, it is important to note that geographical variations might influence these trends. The extensive data on the allocation of MAAs are broadly categorized based on the tropical, temperate, Arctic and Antarctic regions:

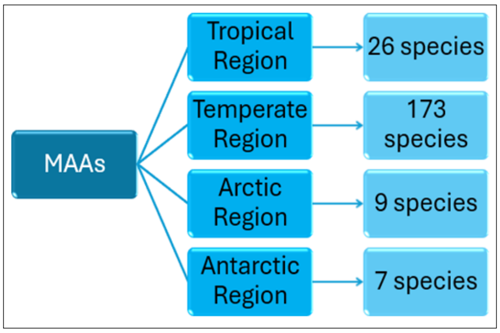

Fig 1: MAAs can be classified based on the region of their growth. Depending on the climatic condition of a region, there are certain number of MAAs species that have been characterised

a. **Tropical Zone:** Even before the depletion of the ozone layer in the stratosphere had started, tropical ecosystems on Earth have been exposed to noticeably extreme levels of ultraviolet radiation (UVR) when compared to regions at higher latitudes [8]. Consequently, aquatic organisms inhabiting these areas have always possessed defence mechanisms to contend with the natural UVR levels. The concept gains credibility from the fact that tropical organisms produce larger quantities and a more diverse range of MAAs (mycosporine-like amino acids). According to studies conducted in the Belizean tropical reefs, renowned for their subtle levels of dissolved organic matter as well as suspended particulates, samples were collected from six species of cyanobacteria and macrophytes. These organisms primarily exhibited the presence of five distinct MAAs, with mycosporine-glycine being a common component in all of them [9]. Also, in a study, algal mats and phytoplanktons collected from the high-altitude tropical Lake Waiau were examined for the allocation of MAAs [10]. Interestingly, Porphyra-334 emerged as the single predominantly present MAA in the water section, while the mats exhibited a quantitatively greater allocation of MAAs.

b. **Temperate Zone:** During early summer, a notable decrease in stratospheric ozone concentration has been documented over temperate regions, that exhibit low concentrations of light-scattering or light-absorbing particles, as well as humic compounds. This particular combination serves to reduce the extinction coefficient of photosynthetically active radiation (PAR), and ultraviolet (UV) radiation, and, thereby increasing the transparency of these wavelengths within the system. One such exemplary body of water that showcases these characteristics is the Gulf of Maine. Among the twenty-two macrophytes from Maine, mycosporine-glycine was the most prevalent MAA, with asterina-330 and palythene conspicuously absent. Interestingly, warm-temperate macroalgal species found in southern Spain have shown to express MAAs that are allocated at levels two times higher than those observed in polar water species or cold-temperate [11]. Notably, Rhodophyceae from warm-temperate zones exhibited higher MAA allocations than their counterparts from cold-temperate regions. Also, Bangia atropurpurea, a marine red alga [12], which inhabits the upper eulittoral zones, contains four different MAAs, including palythinol, porphyra-334, asterina-330, and palythine, constituting the majority of the MAA allocations.

c. **Arctic Zone:** Among the 22 macroalgal species collected on the Arctic islands, nine species from the upper sublittoral (0-2 m) and eulittoral (0 m) zones exhibited the allocation of MAAs. Interestingly, the species completely devoid of sunscreen pigments were primarily found in the deeper sublittoral zone (2–20 m). Scientists have recorded that after the split of sea ice in the spring, the waters in the Arctic become exceptionally clear. However, as the season progresses, there is a substantial increase in suspended particulates from melted glaciers, leading to a significant reduction in water transmittance. Given that the summer and autumn months of August through September feature the longest days, species inhabiting this environment require a comprehensive UV protection mechanism. In the Arctic zone, the indigenous macroalga Devaleraea ramentaceae has allocated seven distinct MAAs [13], demonstrating its capacity to adapt to shifting irradiances during field experiments.

d. **Antarctic Zone:** Lastly, in the Antarctic zone, MAAs have been observed in a diverse range of ecosystems, underlining the widespread biological response to the harmful effects of incident sunlight in these habitats. Various marine organisms undergo physiological and genetic changes due to the reducing of the Antarctic ozone layer during springtime and the lengthening of daylight hours. In a study conducted on the Antarctic peninsula, encompassing 57 species, including 8 algal species, it was revealed that 90% of them allocated MAAs. Remarkably, the majority of these algae species were found in intertidal areas. This observation lends support to the theory that organisms had evolved specific techniques to reduce the adverse effects of unrestricted UV exposure long before [14]. A distinct MAA allocation profile was observed in the majority of organisms during the collection of algal samples in McMurdo Sound, Antarctica, in the Spring season. This collection included 38 distinct species of marine organisms, including 2 algae. While the overall allocation of MAAs was equal in the case of the red alga Iridaea cordata at both sites, other species generally exhibited a greater quantity and concentration of MAAs at the Peninsular site [15]. The two most prevalent MAAs in Antarctic diatom species are porphyra-334 and shinorine. Interestingly, the Antarctic macroalgal population thriving in the eulittoral and sublittoral zones exhibits abundant allocation of various MAAs [16]. Among the 36 macroalgal species that were analysed, porphyra-334 and shinorine were found to be most dominant [17].

e. **Aquaculture:** In aquaculture, MAAs are applied to safeguard aquatic organisms from the harmful effects of UV exposure [22]. This application is essential in outdoor aquaculture facilities and hatcheries where marine life is vulnerable to UV exposure. MAAs act as a natural barrier, reducing UV-induced stress in aquatic species [23] and contributing to their overall well-being. By supporting the health of marine organisms, MAAs enhance the success and sustainability of aquaculture operations.

Radiant Elixir: Exploring Maas in Applications, Patterns, and Implications

a. Applications

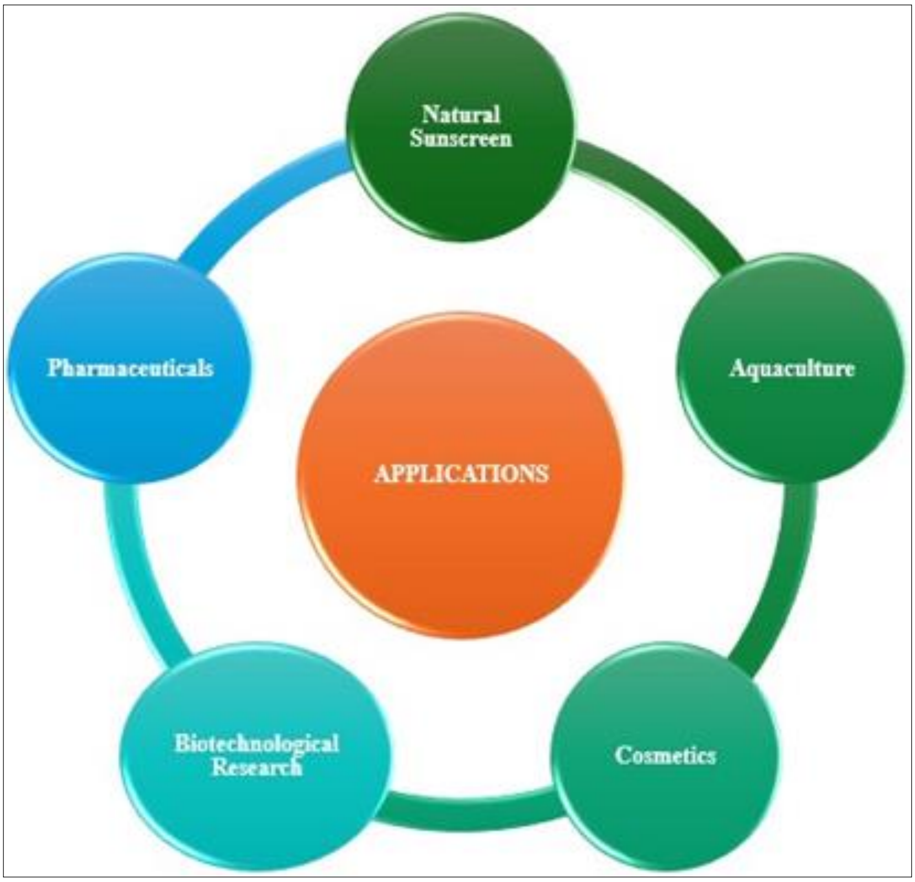

Fig 2: MAAs are involved in a wide range of fields. A few examples of the same are mentioned here

- **Pharmaceuticals:** MAAs are gaining attention in the field of pharmaceuticals because of their antioxidant properties and the ability to shield against UV radiation. These properties are of focus for potential therapeutics [18]. MAAs have shown promise in wound healing and tissue repair, where their antioxidant capabilities may help reduce oxidative stress [19] and support the body's natural healing processes. Additionally, their UV protection potential could be explored for preventing UV-induced skin conditions or complications [20].
- **Natural Sunscreens:** MAAs are used as natural sunscreen ingredients owing to their capacity to absorb and dissipate UV radiation. These compounds act as a protective shield against harmful UV rays, making them a sustainable and eco-friendly alternative to synthetic

sunscreen chemicals [21]. When applied tropically, they provide a physical barrier that decreases the reach of UV radiation into the skin, effectively preventing sunburn and long-term skin damage.

- **Cosmetics:** MAAs are integrated into cosmetics, including sunscreens and anti-aging skincare products, due to their proven UV protection and antioxidant properties. When incorporated into skincare formulations, they offer multifaceted benefits. MAAs not only avoid skin damage from UV-induced damage, but they also help combat premature aging by neutralizing free radicals that get produced by UV radiation. This makes them a valuable addition to products aimed at maintaining youthful and healthy skin [24].

- **Biotechnology Research:** MAAs are subjects of biotechnology research aimed at understanding their molecular properties and potential applications. Researchers are investigating the mechanisms through which MAAs provide photoprotection and their broader functions in various organisms [25]. This research may uncover innovative applications and inspire the development of new technologies or products based on the unique properties of MAAs.

b. Patterns

- **Potential Therapeutic Agents:** Research into the pharmaceutical potential of MAAs suggests that they may have therapeutic applications in medical fields. Their antioxidant properties and UV protection capabilities make them promising candidates for wound healing, tissue repair, and potentially preventing or managing skin conditions associated with UV exposure [26].

- **Consumer Demand:** The inclusion of MAAs in products is driven by consumer preferences for natural and safe skincare and sun protection solutions. Consumers are increasingly seeking effective products with fewer synthetic chemicals [21], reflecting a broader trend toward eco- conscious and health-conscious choices.

- **Eco-friendly Solutions:** The use of MAAs in different applications aligns with the growing demand for eco-friendly and sustainable alternatives. As natural compounds, MAAs provide an environmentally conscious choice [27], reducing the reliance on synthetic chemicals that can have deleterious effects on ecosystems and human health.

- **UV Protection:** MAAs consistently serve as a means of protection against harmful UV radiation. Their primary function is to absorb and dissipate UV rays, to inhibit them from affecting organisms [28]. This pattern is observed across various ecosystems and applications where UV protection is needed.
- **Aquatic Enhancement:** The application of MAAs in aquaculture is crucial for enhancing the success and sustainability of marine organism cultivation [22]. UV protection ensures that aquatic species thrive and reproduce in outdoor facilities, ultimately benefiting the aquaculture industry by improving yields and reducing losses due to UV-induced stress.

c. Implications

- **Effective Sun Protection:** MAAs in sunscreen and skincare products provide a natural and highly effective means of UV protection. By reducing the risk of skin cancer, sunburn, and other UV- related skin damage, MAAs contribute to long-term skin health and well-being [29].

- **Skin Health:** The incorporation of MAAs into skincare formulations helps maintain healthier and more youthful skin. MAAs' antioxidant properties help counteract the effects of UV-induced oxidative stress, preventing premature aging [30] and promoting overall skin resilience and appearance.

- **Sustainable Aquaculture:** The use of MAAs in aquaculture supports sustainable seafood production by safeguarding aquatic organisms from UV radiation [31]. This contributes to the health and productivity of marine life, benefiting both the aquaculture industry and consumers.

- **Medical Advancements:** MAAs hold promise for medical advancements, particularly in wound healing and tissue repair [32]. Their potential applications in pharmaceuticals may lead to innovative treatments that improve healing outcomes and enhance patient well-being.

- **Innovation Potential:** Niche applications of MAAs in food and beverages suggest the potential for innovative product developments. As consumers increasingly seek health-conscious choices, there is room for the creation of new food and beverage formulations with added antioxidant benefits (Roy *et al*., 2021) [33].

- **Scientific Insights:** Ongoing research into MAAs provides valuable insights into their photoprotective mechanisms and broader functions in ecosystems and organisms (Whittock *et al*., 2021) [34]. This knowledge fuels scientific progress and innovation, potentially leading to new discoveries and applications in various industries.

Conclusion

In the face of pressing global environmental challenges, such as climate change and the increasing threat of harmful UV radiation, the ecological significance of MAAs (Mycosporine-Like Amino Acids) has become a focal point of scientific inquiry. UV radiation, both UV-A and UV-B, plays a pivotal role in shaping ecosystems, affecting organisms genetically and disrupting photosynthesis in a wide spectrum of species. The ecological implications of increased UVR exposure are complex, influenced by species-specific susceptibility and habitat variability. Organisms have evolved an array of adaptive measures to cope with elevated UV radiation, ranging from seeking sheltered habitats to synthesizing protective compounds. Notably, MAAs have emerged as a fascinating category of compounds produced by various photosynthetic organisms to provide photoprotection. These compounds, characterized by their ability to absorb UV radiation, are of particular interest due to their potential for use in human sunscreens as an environmentally friendly alternative to synthetic compounds. With commercial sunscreens raising concerns about impact on the environment, from contamination in marine ecosystems to potential human health risks, the natural origin and photoprotective qualities of MAAs make them a promising alternative for sunscreens that align with environmentally conscious consumer preferences. In conclusion, the study of MAAs and their ecological allocation patterns sheds light on innovative approaches to tackle the challenges posed by increasing UV radiation. These compounds not only offer protection to organisms in their native habitats but also hold the potential to provide sustainable and safe solutions for human protection while addressing concerns about the effect of synthetic chemicals on the environment. With constant depletion of the integrity of our environment at our own hands, MAAs exemplify the intriguing interplay between nature's solutions and the challenges of our modern world.

Over the ages, there has been a rapid increase in the damage caused to the stratospheric ozone layer, resulting in greater UV radiation reaching us. Though MAAs have been proved to be excellent absorbers of these UV rays, isolation of pure MAAs still remains a challenge. Also, though currently a lot of progress has been reached with respect to the understanding of the biochemical pathways and large-scale production of MAAs, there is a lot still to be known. The discovery of localised sited of MAAs in chloroplasts, and the trapping of the system to induce MAAs pathway into higher plants would allow us to study the mechanism of MAAs in greater details. MAAs is also being researched as anti-cancerous agent, anti-ageing agent and for its anti-inflammatory actions. We still have a long way to cover, however the complete investigation of MAAs will help us to discover an effective therapeutic system for a variety of UVR syndromes of the skin.

References

1. Bepfs PF, Coba F De, Aguilera J, Korbee N, De G. UVA and UVB photoprotective capabilities of topical formulations containing mycosporine-like amino acids (MAAs) through different biological effective. Available from: https://doi.org/10.3390/md17010055.
2. Pathak J. Ultraviolet radiation and salinity-induced physiological changes and scytonemin induction in cyanobacteria isolated from diverse habitats,2022:12(3):3590–606.
3. Singh SP, Sinha RP, Häder MKD. Mycosporine-like amino acids (MAAs) profile of a rice-field cyanobacterium Anabaena doliolum as influenced by PAR and UVR. Plant Biol, 2008, 225–33. Available from: https://doi.org/10.1007/s00425-008-0822-1.
4. Rosic NN. Recent advances in the discovery of novel marine natural products and mycosporine-like amino acid UV-absorbing compounds. Mar Drugs, 2021, 7053–67.
5. Kockler J, Oelgemöller M, Robertson S, Glass BD. Photostability of sunscreens. J Photochem Photobiol C Photochem Rev,2012:13(1):91–110. Available from: https://doi.org/10.1016/j.jphotochemrev.2011.12.001.
6. Schneider Félix L, Vega J, Chaves P, Álvarez-Gómez F, Korbee N, Bonomi-Barufi JG. Photoprotection properties of marine photosynthetic organisms grown in high ultraviolet exposure areas: Cosmeceutical applications. Algal Res,2020:49:101956. https://doi.org/10.1016/j.algal.2020.101956
7. Jeffrey HS, Dunlap WC, Vesk M, Groenewoud KS. Occurrence of UVA- and UVB-absorbing compounds in 152 species (206 strains) of marine microalgae. Mar Ecol Prog Ser,1999:189:35–51. Available from: https://doi.org/10.3354/meps189035.
8. Frederick HE, Haywood EK, J. E. S. Solar ultraviolet radiation at the Earth’s surface. Photochem Photobiol,1989:50(4):443–50. Available from: https://doi.org/10.1111/j.1751-1097.1989.tb05548.x.
9. Karsten T, Wiencke C. A survey of the distribution of UV-absorbing substances in tropical macroalgae. Phycological Res,1998:46(4):271–9. Available from: https://doi.org/10.1046/j.1440-1835.1998.00144.x.
10. Kinzie AT, Lesser MP, R. A. B. Effects of ultraviolet radiation on primary productivity in a high-altitude tropical lake. Hydrobiologia,1998:385(1):23–32. Available from: https://doi.org/10.1023/a:1003489121985.
11. Banaszak MP, Kuffner IB, Ondrusek MA, T. L. Relationship between ultraviolet (UV) radiation and mycosporine-like amino acids (MAAs) in marine organisms. Bull Mar Sci,1998:63(3):617–28. https://doi.org/NA
12. Karsten JA, U. W. Living in the intertidal zone - seasonal effects on heterosides and sunscreen compounds in the red alga Bangia atropurpurea (Bangiales). J Exp Mar Biol Ecol,2000:254(2):221–34. Available from: https://doi.org/10.1016/s0022-0981(00)00280-x.
13. Karsten K, Hanelt D, Tüg H, Wiencke C. The effect of ultraviolet radiation on photosynthesis and ultraviolet-absorbing substances in the endemic Arctic macroalga Devaleraea ramentacea (Rhodophyta). Physiol Plantarum,1999:105(1):58–66. Available from: https://doi.org/10.1034/j.1399-3054.1999.105110.x.
14. Smith LI, W. O. Hyperproductivity of the Ross Sea (Antarctica) polynya during austral spring. Geophys Res Lett,1997:24(3):233–6. Available from: https://doi.org/10.1029/96gl03926.
15. Döhler M, Stappel U, G. H. Pattern of proteins after heat shock and UV-B radiation of some temperate marine diatoms and the Antarctic Odontella weissflogii. Botanica Acta,1995:108(2):93–8. Available from: https://doi.org/10.1111/j.1438-8677.1995.tb00837.x.
16. Bischof D, Wiencke C. UV-radiation can affect depth-zonation of Antarctic macroalgae. Mar Biol,1998:131(4):597–605. Available from: https://doi.org/10.1007/s002270050351.
17. Hoyer U, Sawall T, Wiencke C. Photoprotective substances in Antarctic macroalgae and their variation with respect to depth distribution, different tissues and developmental stages. Mar Ecol Prog Ser,2001:211:117–29. Available from: https://doi.org/10.3354/meps211117.
18. Martins A, Vieira H, Gaspar H, Santos S. Marketed marine natural products in the pharmaceutical and cosmeceutical industries: Tips for success. Mar Drugs, 2014, 1066–101.
19. Wada N, Sakamoto T, Matsugo S. Multiple roles of photosynthetic and sunscreen pigments in cyanobacteria focusing on the oxidative stress.

Metabolites, 2013, 463–83. Available from: https://doi.org/10.3390/metabo3020463.
20. Mohan SV. Microalgal cell biofactory—therapeutic, nutraceutical and functional food applications, 2021.
21. Sen S, Mallick N. Mycosporine-like amino acids: Algal metabolites shaping the safety and sustainability profiles of commercial sunscreens. Algal Res,2021:58:102425. Available from: https://doi.org/10.1016/j.algal.2021.102425.
22. Dionisio Sese ML. Aquatic microalgae as potential sources of UV-screening compounds. Mar Biotechnol,2010:139:5–16.
23. Shick JM, Dunlap WC. Mycosporine-like amino acids and related gadusols: Biosynthesis, accumulation, and UV-protective functions in aquatic organisms. Annu Rev Physiol,2002. Available from: https://doi.org/10.1146/annurev.physiol.64.081501.155802.
24. Vega J, Gómez-Pinchetti JL, Figueroa FL. Cyanobacteria and red macroalgae as potential sources of antioxidants and UV radiation-absorbing compounds for cosmeceutical applications. Mar Drugs,2020:18(12):659. Available from: https://doi.org/10.3390/md18120659.
25. Cassier Chauvat C, Blanc Garin V, Chauvat F Genetic, genomics, and responses to stresses in cyanobacteria: Biotechnological implications, 2021.
26. Chrapusta A, Duchnik K, Bober B, Adamski M, Bialczyk J. Mycosporine-like amino acids: Potential health and beauty ingredients. Mar Drugs,2017:15(10):326. Available from: https://doi.org/10.3390/md15100326.
27. Andreguetti D, Stein EM, Pereira CMP, Pinto E, Colepicolo P. Antioxidant properties and UV absorbance pattern of mycosporine-like amino acids analogs synthesized in an environmentally friendly manner. J Biotechnol, 2013, 1-8. Available from: https://doi.org/10.1002/jbt
28. Chandra R, Pons Faudoa FP, Parra R, Rittmann BE. Effect of ultraviolet exposure on production of mycosporine-like amino acids and lipids by Lyngbya purpurea. Biomass Bioenergy,2020:134:105475. Available from: https://doi.org/10.1016/j.biombioe.2020.105475.
29. Singh A, Čížková M, Bišová K, Vítová M. Exploring mycosporine-like amino acids (MAAs) as safe and natural protective agents against UV-induced skin damage. Antioxidants,2021:10(5):683. Available from: https://doi.org/10.3390/antiox10050683.
30. Kageyama H. Properties of mycosporine-like amino acids: Molecular and cellular mechanisms in the protection, 2019.
31. Klisch M, Hader DP. Mycosporine-like amino acids in the marine dinoflagellate Gyrodinium dorsum: Induction by ultraviolet irradiation. Mar Biol,2000:1(55):178–82.
32. Anti aging E, Orfanoudaki M, Hartmann A, Alilou M, Gelbrich T, Planchenault P, *et al*. Absolute configuration of mycosporine-like amino acids, their wound healing properties and *in vitro*, 1–16.
33. Roy UK, Nielsen BV, Milledge JJ. Antioxidant production in Dunaliella. Appl Sci, 2021, 1–24.
34. Whittock AL, Auckloo N, Cowden AM, Turner MAP, Woolley JM, Wills M, *et al*. Supporting information: Exploring the blueprint of photoprotection in mycosporine-like amino acids. Available from: https://doi.org/10.1093/oxfordjournals.pcp.a074525.