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Microbial-Derived UV-Protective Compounds: A Sustainable Alternative to Chemical Sunscreens

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Sunlight includes ultraviolet (UV) radiation, and it's one of the oldest environmental threats in the world, leading to skin issues like sunburn, pigmentation and tanning, premature aging, and even skin cancer (in severe cases). Commercially available sunscreens are mostly composed of chemical filters like oxybenzone, avobenzone, and octinoxate (Koshti et al., 2022). While effective, concern regarding the safety of these ingredients in sunscreens have been raised due to their observed skin-irritation potential, disruption of hormonal functions and negative impact on environmental health (specifically found to cause coral bleaching). As a result of rapidly growing public health awareness, consumers have greatly increased the demand for safer and more sustainable alternatives in the past few decades (Koshti et al., 2022). As a response to these concerns, scientists have turned their attention to natural pigments produced by microorganisms, which show potential as strong UV-protecting agents and other skin benefits. In addition to absorbing harmful UV radiation, microbial products also contain antioxidant, anti-inflammatory, and antimicrobial properties, making these products potentially efficacious ingredients in skincare. Additionally, their natural origin and multifunctionality have the potential to be developed into a sustainable approach for sun protection formulations (Choksi et al., 2020).

Microbial Diversity and UV Exposure

Microorganisms adapted to a wide variety of environments including deserts, salt flats, deep sea hydrothermal vents and the polar ice caps. In regions that experience high UV levels, microbes tend to produce pigments as a biochemical mechanism of protection against UV-induced damage to their cellular components. These pigments act as biological sunscreens by protecting proteins and DNA from damaging radiation in both UV-A and UV-B light. For instance, cyanobacteria growing on sunlit rocks and soil tend to develop red, brown, or golden mats laden with protective pigments such as scytonemin and carotenoids. Likewise, pigment-containing bacteria inhabiting salt lakes, coastal regions, as well as even contaminated areas possess an impressive resistance against UV radiation as a result of such adaptations. These distinctive features have drawn the interest of researchers wanting to exploit or mimic them for safer and more eco-friendly sunscreens (Siezen, 2011).

Microbial Pigments' Role in Nature

Microbial pigments exist in various forms, with each providing unique protective functions against environmental stress factors. Carotenoids, for example, are lipid-soluble pigments that can neutralize free radicals and absorb UV radiation efficiently. Melanin is a broad-spectrum UV protector owing to its colour and capacity to absorb both the UV-A and UV-B rays (Kiki, 2023). Compounds such as violacein and prodigiosin not only possess attractive colours but also antimicrobial and protective effects against UV. Flexirubins from *Flavobacteria* absorb throughout the UV-visible spectrum and provide photoprotection (Kiki, 2023). Another necessary group consists of mycosporine-like amino acids (MAAs) that are water-soluble compounds and absorb strongly in the UV-B region. Scytonemin, a brown pigment excreted extracellularly from cyanobacterial cells, has a strong UV-A filtering capability (Kiki, 2023). These pigments not only provide UV protection but also affect microbial behaviour, symbiosis, and survival under extreme conditions (Kiki, 2023).

MAAs and Scytonemin: Nature's UV Protectants

Of all the microbial pigments, MAAs and scytonemin have been studied most extensively for their photoprotective potential. MAAs are water-soluble, colourless, and photostable substances that absorb UV radiation between 310–360 nm (Sathiabalan et al., 2023). Shinorine, porphyra-334, and mycosporine-glycine are common forms of them that occur in cyanobacteria, algae, dinoflagellates, and even fungi. In addition to UV absorption, MAAs function as antioxidants, shielding skin from oxidative damage and decelerating visible signs of aging (Sathiabalan et al., 2023). In contrast, scytonemin is a UV-A-absorbing lipid-soluble pigment, particularly around 384 nm. It is ubiquitously present in the sheaths of cyanobacteria that live in UV-radiative environments such as hot springs or high-altitude areas (Sathiabalan et al., 2023). Notably, species such as *Nostoc flagelliforme* can synthesize both MAAs and scytonemin, providing full-spectrum UV protection—a great natural template for sunscreen design (Sathiabalan et al., 2023

Genomics and Biosynthesis Insights

Improvements in genomics and synthetic biology have revealed the biosynthetic pathways for microbial pigments. MAAs: From sedoheptulose-7-phosphate (an intermediate of the pentose phosphate pathway), through the action of a four-gene operon with the classical enzymes for the synthesis of shinorine and related metabolites (Smith et al., 2023). Scytonemin: Through an 18-gene enhanced cluster induced by exposure to UV-A radiation, resulting in numerous steps converting aromatic amino acids to its unique polycyclic structure (Smith et al., 2023). With this genetic information, researchers are now able to genetically engineer bacteria such as *Escherichia coli* or *Bacillus subtilis* to synthesize these pigments in bulk, avoiding the necessity of extracting them from natural environments. This now presents opportunities for sustainable, in-the-lab production of natural ingredients for sunscreen (Smith et al., 2023).

Skincare and Therapeutic Applications

Microbial pigments hold enormous potential for use in skincare as multi-tasking agents. These are UV filters that can match or even surpass synthetic chemicals in preventing harm caused by radiation exposure. Moreover, their anti-inflammatory and antioxidant activity makes them effective in treating sensitive skin or acne-prone skin (Choksi et al., 2020).

There are even some pigments that provide antimicrobial properties, which can be used to prevent or treat skin infections. There are already several MAAs in existing cosmetic products, including Helioguard 365, a natural additive to sunscreen. Scytonemin, likewise, has been of interest in pharmaceutical applications, such as potential use in treating skin inflammation and even cancer. Growing demand for reef-safe, clean beauty products will see these microbial ingredients play a significant role in the industry of cosmetics (Choksi et al., 2020).

Technological Advancements

Current biotechnologies are speeding up the manufacturing and use of microbial sunscreens. Microbes can be engineered using synthetic biology methods for high-productivity pigment production, especially MAAs and scytonemin. Bioreactors enable the microbes to be grown under optimal conditions to have constant and scalable production. Omics technology, such as transcriptomics and metabolomics, assists in the identification of essential genes and pathways for optimizing pigment yield. In addition, CRISPR-Cas9 provides an accurate instrument for the manipulation of microbial genomes to increase biosynthetic efficiency. Collectively, these advancements are bringing microbial sunscreens to near large-scale commercial potential (Koshti et al., 2022).

Environmental and Regulatory Considerations

In comparison to conventional chemical UV blockers, microbial pigments are biodegradable, reef-safe, and environmental-friendly. Their incorporation has the potential to reverse the harm done to the environment by traditional sunscreens, particularly in oceanic environments. Nonetheless, regulatory agencies such as the FDA and EMA must conduct extensive testing before these pigments can be used on a larger scale to ascertain efficacy and safety. Toxicological tests, skin sensitivity testing, and long-term exposure studies are essential for gaining approval. With increasing adaptation of regulations to encompass bio-based and genetically modified ingredients, microbial sunscreens are poised to experience wider acceptance (Smith et al., 2023).

Conclusion

Pigments produced by microorganisms are a great alternative to the synthetic UV absorbers typically used in sunscreen that has UV-absorbing, antioxidant and antimicrobial properties, and is environmentally safe. MAAs and scytonemin can be used as natural scaffolds for broad-spectrum photoprotection. As genomics, metabolic engineering, and biotechnology develop, pigment- and secondary metabolite-based compounds derived from microorganisms will revolutionize the skincare and therapeutics industries (Kiki, 2023; Sathiabalan et al., 2023). Future work needs to focus on engineering biosynthetic pathways, production at a larger scale, and regulatory considerations to expedite the implementation of their use in the marketplace for commercial UV protection products.

References

1. Choksi, J., Vora, J., & Shrivastava, N. (2020). Bioactive pigments from isolated bacteria and its antibacterial, antioxidant and sun protective application useful for cosmetic products. *Indian Journal of Microbiology*, *60*(3), 379-382.
2. Darvhankar, M, Kasundra, S., Kamdar, J., Ranga, A. D., & Bera, S. K. (2019). Identification of true hybrid progenies in Peanut using simple sequence repeat (SSR) Markers. *Plant Cell Biotech and Molecular Biology*, ***20***, 14-21.
3. Jasani, M., Kamdar, J., Bera, S., Sunkad, G., & Bera, S. (2021). Novel and stable major QTLs conferring resistance to peanut bud necrosis disease and identification of resistant high yielding peanut breeding lines. *Euphytica*, ***217***(6), 105.
4. Jasani, M. D., Maurya, A. K., Dash, P., Kamdar, J. H., Sunkad, G., Mahatma, M. K., & Bera, S. K. (2018). Identification of peanut interspecific pre-breeding lines resistance to peanut bud necrosis disease (PBND): Field screening, morphological and biochemical parameters. *International Journal of Current Microbiology and Applied Sciences*, ***7***(2), 1928-1939.
5. Kiki, M. J. (2023). Biopigments of microbial origin and their application in the cosmetic industry. *Cosmetics*, *10*(2), 47.
6. Koshti, R., Jagtap, A., Noronha, D., Patkar, S., Nazareth, J., Paulose, R., ... & Chakraborty, P. (2022). Evaluation of antioxidant potential and UV protective properties of four bacterial pigments. *Microbiology and Biotechnology Letters*, *50*(3), 375-386.
7. Sathiabalan, N., Ong, K. W., & Chew, A. L. (2023). Effects of UV radiation on human skin and its microbiota: a review on microbial UV sunscreens. *Periodicum biologorum*, *125*(3-4), 147-154.
8. Siezen, R. J. (2011). Microbial sunscreens. *Microbial biotechnology*, *4*(1), 1.
9. Smith, M. L., O'Neill, C. A., Dickinson, M. R., Chavan, B., & McBain, A. J. (2023). Exploring associations between skin, the dermal microbiome, and ultraviolet radiation: advancing possibilities for next-generation sunscreens. *Frontiers in Microbiomes*, *2*, 1102315.