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Types of Melanin Pigments and their Applications

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ABSTRACT

Melanin is a multifunctional pigment in many different organism and its special properties caused rising interest for research. Of its microbial sources, one promising producer is *Streptomyces*. After being initially discovered in this genus its melanin biosynthesis was extensively studied, which eventually unfolded the great versatility of melanins. Importantly, melanin from *Streptomyces* shows other biological activities such as antioxidant, antimicrobial and anti canceravitas. Its antioxidant properties can help to scavenge free radicals and combat oxidative stress, thus qualifying it for use as medicinal ingredient. It also helps with antimicrobial effects and it becomes an excellent choice for natural preservation. With its role in the lives of medical science, it also found benefits to a diverse group with different industrial applications for *Streptomyces* melanin.. Its pigmentation properties have been exploited for dyes, cosmetics, and food colorings. Furthermore, its biocompatibility and stability have opened avenues for its use in materials science and environmental remediation. Current study focuses on optimizing melanin production, characterizing its structural variations, and elucidating the mechanisms underlying its biological activities. the potential applications of Streptomyces melanin are expected to grow, making it a valuable resource across multiple fields.

Keywords: pigmentation, Bacteria, Enzyme, Function, Metabolite

Introduction

Melanin is a complex pigment with multiple biological functions, produced by a variety of organisms throughout evolutionary history. Although its production by bacteria (particularly *Streptomyces*) is a recent discovery, it lives up to the reputation of this genus for producing a variety of bioactive compounds, including antibiotics. *Streptomyces* melanin is usually formed as a secondary metabolite during the stationary growth phase and has the same properties as other types of melanin: it is a dark, insoluble polymer that is UV protective, antioxidant, antimicrobial, and biocompatible (Tran-ly et al., 2020). However, *Streptomyces* bacteria produce melanin can vary between different species. *Streptomyces* melanin has a lot of potential for commercial use, but there are some challenges to address before it can be fully utilized. To make the most of this potential, it's important to find ways to produce melanin more efficiently, create cleaner production processes, and thoroughly assess safety. We also need to learn more about the structure and properties of different types of *Streptomyces* melanin. Despite these challenges, the growing demand for eco-friendly solutions and the unique qualities of *Streptomyces* melanin suggest a bright future. With ongoing research, the use of melanin-producing *Streptomyces* is likely to expand into various fields, leading to the development of new, environmentally friendly products (El-Zawawy et al., 2024).

Melanin Production in *Streptomyces*

Different species of *Streptomyces* are renowned for biosynthesis ability (like antibiotic, antitumor and immunosuppressant etc.) Latest investigations have documented that pigments, including melanin **(a pigment normally involved in the development of aerial mycelia and spores**) are produced by some *Streptomyces* strains. Thus indicating an evolutive benefit of melanin as a protective against environmental strains. Melanin production in *Streptomyces* is an enzymatic process that has not been fully elucidated yet. It is species dependent,

but it includes creating intermediate molecules from tyrosine or tryptophan that give rise to melanin polymers. Tyrosinase and polyphenol oxidase are the main enzymes for this purpose and participate in polymerization of phenolic compounds to provide melanins precursors (Ali & Naaz, 2018).

Characteristics of *Streptomyces* Melanin

Streptomyces bacteria produce type of melanin that sets it apart from other living things. usually a dark brown or black and is made up of very large, complex molecules that differ depending on the specific bacteria and its environment. It's packed with phenolic and quinone compounds, which give it powerful antioxidant and metal-binding abilities. Amazingly, Streptomyces melanin is incredibly resistant to damage from physical forces or chemicals. Because of its impressive properties, scientists are excited about its potential uses, especially in medicine, where its antibacterial and antioxidant effects could be very beneficial

Types of melanin

1. Eumelanin

Eumelanin, the predominant melanin type in bacteria, humans and many animals(Figure1), is responsible for the spectrum of brown to black pigmentation observed in skin, hair, and eyes. It exists in two forms: brown eumelanin, less polymerized and associated with red hair, and black eumelanin, highly polymerized and linked to dark hair, skin, and eye color. As a polymer composed of indole-5,6-quinone units, eumelanin is widely distributed in humans, mammals, birds, reptiles, and certain invertebrates. Its primary function is photoprotection, acting as a shield against the harmful effects of UV radiation.

2. Pheomelanin

Pheomelanin is a type of melanin that contributes to red, yellow, and orange pigmentation in humans and animals. It combines with eumelanin but is less common than its heavier counterpart. Unlike eumelanin, pheomelanin has a lower molecular weight and higher sulfur content and is composed of benzothiazine (BTZ) 2-Acetyl-4-S-cysteaminophenol unitica as well as pyrrole units. It creates shades of yellow and orange -commonly seen in people with red hair and fair skin. Pheomelanin, unlike eumelanin, does not protect against UV radiation as well.

3. Allomelanin

re truly amazing substances! These pigments aren't just found in animals – you can also discover them in plants, fungi, and even bacteria. Unlike their better-known cousins, eumelanin and pheomelanin, allomelanins have their own unique makeup and characteristics. It's fascinating to think about the variety of life forms that share these intriguing pigments. These pigments, created from polyphenols, play crucial roles in protecting organisms from UV radiation, acting as antioxidants, and binding to metals.

4. Pyomelanin

Streptomyces bacteria produce a dark pigment derived from homogentisic acid (HGA), a metabolic intermediate. This HGA accumulates and spontaneously transforms into pyomelanin, a natural pigment possessing antioxidant and antimicrobial properties, suggesting its potential for diverse applications (Choi, 2021).

The Precursors and biosynthesis of four melanin pigment can be observed in (Figure 4)

5. Other Types of Melanin

While everyone knows about eumelanin and pheomelanin – the stuff that gives our skin and hair color – there are actually other types of melanin out there. One fascinating kind is neuromelanin, which is found in our brains. Scientists aren’t entirely sure what it does yet, but they think it might help protect our brain cells and balance out some of the chemical reactions happening there.

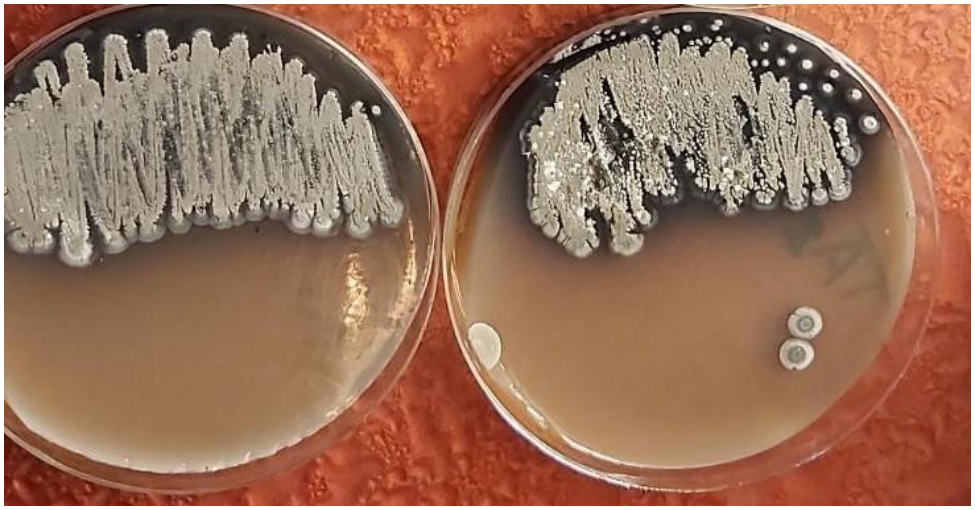

Figure (1) melanin pigment production by *streptomyces* sp on agar medium

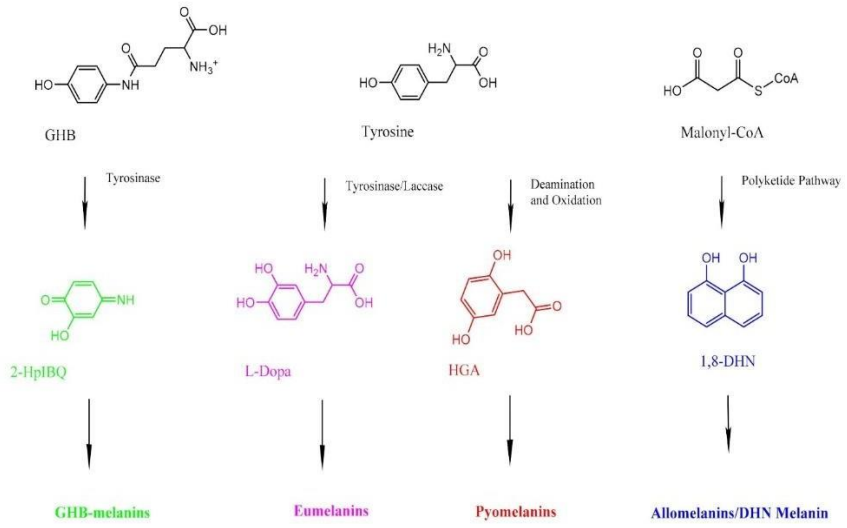

Figure (2) types of melanin pigment and biosynthesis (Mattoon *et al*., 2021)

Applications of *Streptomyces* Melanin

Streptomyces melanin, with its strong attraction to metal ions, shows promise as a natural solution for cleaning up polluted water and soil. This substance can effectively capture and hold onto heavy metals, trapping them in harmless solid clumps that are easy to remove. Additionally, research has highlighted its ability to act as an antioxidant and combat harmful bacteria, suggesting potential uses as a food preservative or even a beneficial ingredient in our diet. **Bioremediation:** Streptomyces melanin is highly useful for the effective removal of heavy metals from wastewater or polluted soils. Melanin readily binds metal ions to form insoluble complexes which makes it easy for the melanin to be removed from its environment. **Antioxidant and Antimicrobial Agents:** Extensive studies have identified that Streptomyces melanin possesses antioxidant and antimicrobial activities. This indicates its possible application as a natural preservative and/or functional food ingredient. **Biomaterials:** These properties of S. melanin suggest it as a suitable biocompatible and stable material candidate for biomedical applications. In the case of medical implants, it can serve as a coating that enhances biocompatibility and more importantly blocks biofilm formation. In addition, melanin-based hydrogels were prepared as dual hydrogel and drug delivery for tissue engineering applications **Pigment and Dye:** The intense color of Streptomyces melanin makes it a potential natural pigment for various applications, including cosmetics, textiles, and food **Biofuel Production:** Some studies have explored the possibility of using Streptomyces melanin as a precursor for biofuel

production (Abd-EL-Aziz et al., 2024) Melanin can be converted into bio-oil through pyrolysis, which can be further processed into liquid transportation fuels.

Conclusion

Living beings naturally produce melanin, they are nature at its best. his natural wonder can neutralize harmful stuff, cling to metals, and tough it out in the roughest conditions.this biopolymer with promising applications in various fields. Its unique properties like : antioxidant activity, metal binding capacity, and stability, make it a valuable resource for developing sustainable and environmentally friendly technologies. Further research is needed to fully understand the biosynthetic pathways of Streptomyces melanin and to optimize its production for commercial applications.

References:

[1] Tran-Ly AN, Reyes C, Schwarze FWMR, Ribera J. Microbial production of melanin and its various applications. World J Microbiol Biotechnol. 2020 Oct 12;36(11):170.

[2] El-Zawawy, N.A., Kenawy, ER., Ahmed, S. *et al.* Bioproduction and optimization of newly characterized melanin pigment from *Streptomyces djakartensis* NSS-3 with its anticancer, antimicrobial, and radioprotective properties. *Microb Cell Fact* **23**, 23 (2024).

[3] Ali SA, Naaz I. Biochemical aspects of mammalian melanocytes and the emerging role of melanocyte stem cells in dermatological therapies. Int J Health Sci (Qassim). 2018 Jan-Feb;12(1):69-76. PMID: 29623021; PMCID: PMC5870308.

[4] ENDO, Kohki, et al. Characterization of mutants defective in melanogenesis and a gene for tyrosinase of Streptomyces griseus. *The Journal of Antibiotics*, 2001, 54.10: 789-796.

[5] Choi KY. Bioprocess of Microbial Melanin Production and Isolation. Front Bioeng Biotechnol. 2021 Nov 16;9:765110.

[6] Mattoon ER, Cordero RJB, Casadevall A. Fungal Melanins and Applications in Healthcare, Bioremediation and Industry. *Journal of Fungi*. 2021; 7(6):488

[7] Abd-EL-Aziz, A.S., Abed, N.N., Mahfouz, A.Y. *et al.* Production and characterization of melanin pigment from black fungus *Curvularia soli* AS21 ON076460 assisted gamma rays for promising medical uses. *Microb Cell Fact* **23**, 68 (2024).