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Types of Melanin Pigments and their Applications

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ABSTRACT

The pigment known as melanin, which has diverse functions in a number of organisms, has become an intriguing target for scientists to investigate further due to its unique properties. Streptomyces, one type of bacteria that produces melanin, was the original location from which scientists derived their understanding of how melanin is produced through biosynthesis, and through a series of studies, the variety of functions provided by melanins have been revealed. Another aspect of Streptomyces melanin is that it can be used for other purposes, namely as an antioxidant, antimicrobially, and anticancer agent due to its ability to eliminate free radicals and alleviate the symptoms of oxidative stress. Thus, it may be incorporated into medicinal products as a source of natural antioxidants. The antibacterial properties of melanin also make it a good candidate for the preservation of food without the use of chemicals or artificial additives. Melanin will continue to provide value in the medical field; however, it has also been used by many industries beyond medicine. The dyeing of textiles, cosmetics, and the coloring of food products are all examples of how the pigmentation characteristics of Streptomyces melanin are being utilized in today's marketplace. Its biocompatibility and stability have also opened up new possibilities for the application of melanin in various areas including material science and environmental cleanup. The current work includes work directed toward optimizing production of melanin and establishing the structural differences in the various types of melanin found in Streptomyces and characterizing their possible mechanisms of action. The potential use of Streptomyces melanin will continue to expand, which will result in Streptomyces melanin as a valuable source for many disciplines..

Keywords: pigmentation, Bacteria, Enzyme, Function, Metabolite

INTRODUCTION

Melanin, or melanic pigment, is an important component in many biological processes and is produced in a variety of ways over time by many different organisms. Melanin production from bacteria (Streptomyces genus), however, has only recently been discovered and is consistent with the immense diversity of bioactive compounds produced by this genus (i.e., antibiotics). Streptomyces melanin is produced as a secondary metabolite typically produced during stationary growth and has the same characteristics as other types of melanin such as it being dark-colored, insoluble, UV-protective, antioxidant, antimicrobial, and biocompatible (Tran-ly et al., 2020). However, there is also much variability among Streptomyces then when it comes to melanin production. Thus, while commercial use of Streptomyces melanin has great potential, there are several things that need to be accomplished prior to full implementation. Therefore, to maximise this opportunity for use of melanin, identification of more efficient methods of production, development of more environmentally friendly production methods and thorough evaluations of safety must be addressed. In order to gain a better understanding of the various types of Streptomyces melanin, we will need to look into how their structure and properties are formed. Given the rising interest surrounding eco-friendly solutions, as well as the unique properties exhibited by Streptomyces melanin, there should be many future possibilities for our work. As research continues, it is very possible that melanin producing species of Streptomyces will be used on a larger scale in different areas, resulting in numerous new eco-friendly items being produced. (El-Zawawy et al., 2024).

Melanin Production in *Streptomyces*

Different species of *Streptomyces* Streptomyces species are well-known for their ability to produce bioactive compounds (such as antibiotics, antitumor agents, and immunosuppressants), and evidence is accumulating that certain pigments (specifically melanin) are also produced by some strains of Streptomyces. While melanin is a pigment that is used in the formation of aerial hyphae and conidia, it can also be postulated as a product resulting from the evolutionary adaptation of Streptomyces to defend them against environmental agents. The mechanisms involved in the production of melanin are still poorly understood and differ among species of Streptomyces.

However, the process involves the synthesis of intermediate compounds derived from either tyrosine or tryptophan, which can ultimately generate melanin polymer molecules through the enzymatic actions of tyrosinase and polyphenol oxidases. Both tyrosinase and polyphenol oxidases act as primary catalyzers for the polymerization of phenolic substrates required to produce the melanin precursor materials necessary to form melanin polymers. (Ali & Naaz, 2018).

Characteristics of *Streptomyces* Melanin

Streptomyces Bacteria produce a distinct form of melanin that distinguishes them from other organisms. Melanin produced by bacteria is usually dark brown or black in color, and consists of very large and complex molecules that vary based on the type of bacteria and the conditions in their environment. The molecules contain large quantities of phenolic and quinons giving the bacteria the ability to bind to metals and act as an effective antioxidant. Streptomyces bacterial melanin is extremely resilient to chemical or physical destruction. Scientists are enthusiastic about the future applications of bacterial melanin due to its special properties - particularly in the field of medicine, where its potential antibacterial and antioxidant function could significantly benefit patients.

TYPES OF MELANIN

1. Eumelanin

Eumelanin is a form of melanin which provides the brown to black pigments in humans, bacteria and many animals (shown in figure one). Eumelanin is made up of two distinct forms of pigments: Eumelanin that is brown with lower levels of polymerization and is therefore usually associated with having red hair; and Eumelanin which is black with higher levels of polymerization, associated with dark colored hair, skin and eyes. Eumelanin is a polymer that is composed of indole-5,6-quinone units, distributed throughout human, mammal, bird, reptile, and some invertebrate species. The main biological function of eumelanin is to provide protection from solar ultraviolet radiation by acting as an antioxidant..

2. Pheomelanin

Pheomelanin is a This type of melanin contributes to the colour red, yellow, and orange in humans and animals. It occurs in combination with eumelanin but is produced in amounts much less than its heavier cousin (eumelanin). Additionally, pheomelanin is lighter in molecular weight than eumelanin, contains much more sulphur than eumelanin, and is composed of both benzothiazine (BTZ)-type 2-acetyl-4-S-cysteinyl-phenol unit and pyrrole units. Pheomelanin produces yellow and orange shades and is commonly found in those with light skin and red hair. Unlike eumelanin, pheomelanin does not provide any UV protection to the skin..

3. Allomelanin

Allomelanin pigments are also awesome organic compounds. They can be found in not only animals but also in other organisms, such as plants, fungi and bacteria. Allomelanins are unique in thatthey are not eumelanin or pheomelanin, which are more commonly known. The wide range of organisms that contain these unique pigments is really interesting. Polyphenols are used to create allomelanins, and allomelanins help organisms protect themselves from ultraviolet light and provide antioxidant activity and bind with metals..

4. Pyomelanin

Streptomyces bacteria produce a dark pigment derived from homogentisic acid (HGA), a metabolic intermediate.

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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

Eumelanin and pheomelanin are well known by most people – they are what gives colour to our skin and hair. However, there are other types of melanin aside from these two, one very interesting one is neuromelanin, which is found in the brain. The exact function of neuromelanin is not yet known, but scientists are hypothesising that it may serve to protect brain cells while also helping to regulate chemical reactions occurring within the brain.

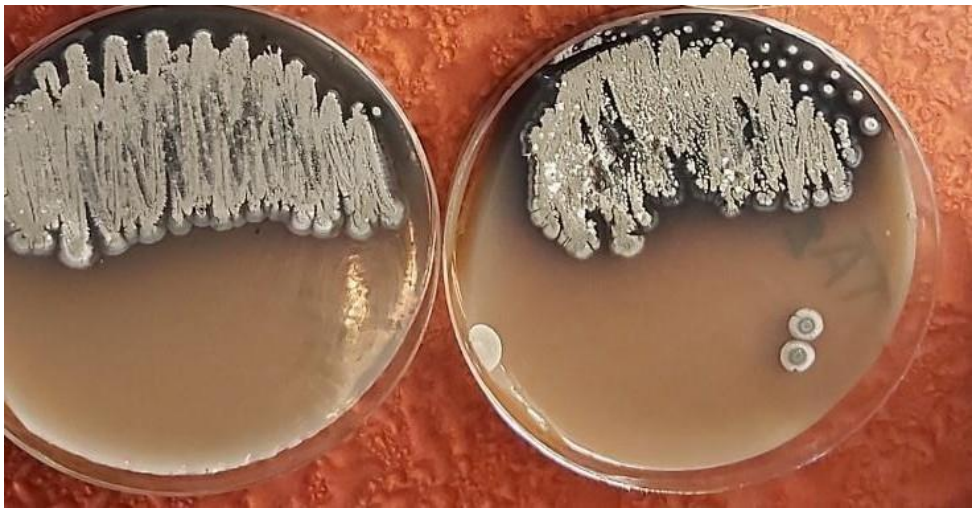

Figure (1) melanin pigment production by *streptomyces* sp on agar medium

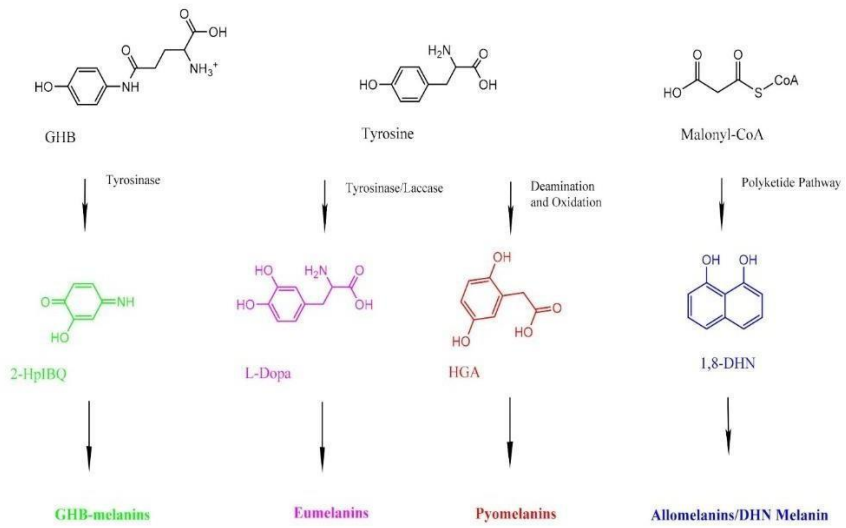

Figure (2) types of melanin pigment and biosynthesis (Mattoon *et al*., 2021) Applications of *Streptomyces* Melanin

Streptomyces Melanin, because of its high affinity for metal ions, could be an excellent natural method of cleaning up contaminated water and soil. Melanin can capture heavy metals and hold them in solid forms that can be readily removed. As well, studies have shown the ability of melanin to possess antioxidant and antibacterial properties, suggesting potential use as a natural preservative in foods or a functional food ingredient. Bioremediation:

Melanin produced by Streptomyces is an effective method for removing heavy metals from wastewater or contaminated soil. Melanin forms insoluble complexes with metal ions, which allows for easy removal of the melanin from the contaminated environment. Antioxidant and Antibacterial Properties: Substantial research has identified the antioxidant and antibacterial properties of melanin produced by Streptomyces. Therefore, there is some potential of these products being used as natural preservatives or functional food ingredients. Streptomyces melanin has properties indicating that it could act as a viable candidate for use as a biomaterial, as a result of its good biocompatibility and stability for use in biomedical applications. In particular, it could be used as an implant coating to improve the biocompatibility of implants, and more importantly the prevention of the formation of bacterial biofilms on the surfaces of implant materials. In addition, melanin-based hydrogels have also been developed, which serve as dual-function hydrogels that can be used as drug delivery systems for tissue engineering applications. Pigments and dyes: Due to its rich color, the intense color of Streptomyces melanin positions it to be able to provide natural pigmenting properties for a number of applications such as cosmetics, textiles and food. Biofuels: A number of researchers have also investigated the potential use of Streptomyces melanin as a raw material for biofuels.

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 things naturally produce melanin in nature's finest form. Melanin can neutralise harmful materials, bind with metals, and endure extreme conditions (such as extreme temperatures). Melanin's properties of being highly antibacterial and having unique qualities (such as being an antioxidant, binding to metals, and being stable) make it a great resource for creating sustainable and environmentally friendly technology. Additional study is required to comprehend the complete biosynthetic routes of Streptomyces melanin, as well as to improve its production for commercial uses.

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