

Applications of Fungal Pigments: A Sustainable Approach Across Industries

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Abstract:With the worldwide interest for natural, environmentally safe and friendly, substitutes for synthetic pigments is on the rise, fungal pigments have emerged as a promising and sustainable solution across various industries. These pigments are advantageous Their ability to grow quickly, be easily produced, and withstand environmental challenges makes them suitable for large-scale use. Furthermore, fungal pigments exhibition significant biological activities, enhancing their versatility.

This review explores the variety of characteristics and industrial uses of fungal pigments. Several research studies have explored their use in the textile sector, particularly for dyeing materials like cotton, silk, and wool. In the cosmetics industry, pigments such as melanin, carotenoids, and lycopene have been utilized in products like sunscreens, lotions, face creams, and anti-aging treatments. In the food industry, certain fungal pigments have already been commercialized as natural food colorants, including Monascus pigments, arpink red from *P. oxalicum*, riboflavin from *A. gossypii*, and β -carotene from *B. trispora*. This review is discussing the vast potential of fungal pigments across these industries, highlighting their promising role in sustainable and natural product development.

Keywords:Fungal pigments, natural colorants, antimicrobial properties, food industry, cosmetic industry, textile industry.

INTRODUCTION-Color has always been a vital aspect of life for all organisms on Earth. For humans, colors significantly influence various areas, like clothing, food, and daily appliance, making life truly vibrant. Usage of pigments as colouring agents in prehistoric times has been revealed through archaeological discoveries Pigments and crushing tools, predicted to be between 350,000 and 400,000 years old, were found in a den at Twin Rivers, Zambia, offering additional evidence of primitive pigment use. (1).For centuries, most colorants were natural and organic, till the development of mauvine, the first

manufactured colorant, by Sir William Henry Perkin in 1856. The innovation transformed the industry, leading to the across-the-board application of artificial colors. These artificial dyes gained popularity because they are easy to produce, have cheap costs, lack unwanted flavors, have remarkable coloring properties, and the fact that only small amounts were necessary to achieve vibrant results.

However, synthetic dyes come with several disadvantages. Dyes like cochineal red, sunset yellow, and tartrazine can cause allergies on their own or when combined with other dyes (2). Additionally, some synthetic dyes used in pharmaceuticals and cosmetic products have been linked to cancer. Due to these health risks, Certain synthetic pigments are prohibited from being used externally. For example, benzidine dyes have been associated with bowel cancer and Carbon black, a pigment frequently found in printing inks, is classified as a potential carcinogen. These drawbacks have driven a growing worldwide interest in natural pigments. Fungal pigments have the potential to fulfil this role.

Fungal pigments can play a crucial role across various industries. Fungi are prevalent in both natural and man-made environments, exhibiting remarkable diversity in species, pigmentation, and morphology. Fungal pigments' significant role in microbial pathogenesis has been widely studied and well-documented. When exposed to environmental stresses like ultraviolet radiation, osmotic pressure, and nutrient shortages, fungi have developed pigmentogenesis as an adaptive survival mechanism. Fungal pigments, considered secondary metabolites, may have been overlooked regarding their significance in cell protection and ecological interactions. Characterized by their diverse structures, these pigments exhibit various bioactivities, including anti-tumor, cholesterol-lowering, anti-obesity anti-atherosclerotic, anti-oxidative, anti-Alzheimer's, and immunosuppressive functions.

FUNGAL PIGMENTS-fungi are recognized for producing a wide variety of colourful metabolites. *monascus* a genus of fungi which represents earliest documented application for a kind of rice which is red in colour. These are typically present in traditional Oriental cuisine, particularly in Japan, Southern China, and Southeast Asia. A wide array of advantageous properties is demonstrated by these pigments.

The majority of our understanding of fungal pigments stems from studies centered on four main genera.: *Aspergillus*, *Penicillium*, *Paecilomyces*, and *Monascus*. Although fungi can produce a varied range of pigments, typically grouped in four main division: melanins, polyketides, azaphilones, and carotenoids azaphilones (3). In this paper, we will explore these categories.

Carotenoids

The word "carotene" derived from carota which is a Latin word first coined in 18th century by wackenroder, who achieved the extraction and purification of the pigment from carrots. Carotenoid names are not based on their structural characteristics; instead, they are derived from the root word "carotene," prefixed by Greek letters (such as α , β , ϵ) to indicate the variations in their terminal groups. As of now, so many species of fungi are discovered to do synthesis of carotene (4). Some of them are mentioned in Fig.1 The bright colors and health advantages of different carotenoids have generated attention in numerous sectors. Similar to carotenoids present in other organism, fungal carotenoids are recognized for their distinctive yellow, orange, and red colors (5).

Melanin's

The formation of fungal melanins occurs through a complicated polymerization process, resulting in compounds that exhibit deep shades of green, black and brown colors. Fungal melanins are characterized by their negative charge and hydrophobic nature. Melanin production plays a crucial role in helping fungi withstand environmental stresses like, extreme temperatures, enzymatic degradation, oxidants, desiccation and UV radiations.

In some pathogenic fungi that affect mammals, melanins might enhance fungal virulence by serving as a mechanism of resistance against the host's immune system (6). Recent research has demonstrated that melanin pigments able to conceal antigens, allowing these pathogens to escape detection by the immune system. This helps the fungi escape phagocytosis and boosts their chances of survival within the host.

Polyketides

A highly diverse collection of natural compounds is represented by polyketides, characterized by their complex carbon skeletons, these compounds are an important source of bioactive molecules with significant pharmaceutical relevance.

Fungal pigments derived from polyketides are produced abundantly by many fungi Particularly prevalent in most genera of filamentous ascomycetes. Two notable classes of these polyketide pigments include anthraquinones and naphthoquinones, which exhibit a variety of colors .

Anthraquinones are able to produce a wide spectrum of colors, ranging from yellows to reds and even blues. Many fungi can produce this metabolite, including HAQNs, the variation in color is associated to the approximately short, conjugated chromophores found in anthraquinones. They tend to exhibit pale yellow hues in their most basic, unsubstituted forms. When substituents are added, these molecules experience significant bathochromic shifts in their absorption maxima, resulting in deeper red and even blue hues. naphthoquinone pigments for instance are generated through numerous species of fungi. Most of them showcase colors that generally range from brown through yellow to orange. Research indicates that in certain *Fusarium* species, the biosynthesis of naphthoquinone pigments is activated by environmental stresses, often taking place during growth inhibition or cessation (7).

Azaphilones

Fungi produce diverse kind of azaphilone pigments, that are synthesized from polyketides. Featuring pyrone-quinone structures, these pigments consist of a bicyclic core that is highly oxygenated and includes a chiral quaternary center. The structural diversity of these compounds stems from the simplicity of nitrogen incorporation into their frameworks.

Azaphilone-producing fungi are found widely in nature and include various types of microscopic fungi, often referred to as "molds," these pigments produce yellow, red, or green colors seen in fungi. These pigments have great potential in food colorant industries (7).

INDUSTRIAL APPLICATIONS OF FUNGAL PIGMENTS

Textile Industry

A wide range of dyes is extensively used by the textile industry and other sectors. The rising demand for pigments has driven expanded research into utilizing filamentous fungi for pigment production. Through biotechnological methods, anthraquinones are synthesized by various fungi, Interestingly, cynodontin, derived from a fungus, produced two anthraquinone dyes that closely resemble traditional synthetic dyes such as Disperse Blue 7 and Acid Green 28n (8). These anthraquinone dyes exhibit properties comparable to standard dyes. Furthermore, anthraquinones produced by different fungi have demonstrated antimicrobial properties. For example, anthraquinones produce a pink pigment used to dye cotton thread. The dyed thread exhibited

outstanding resistance to light, heat, pH changes, and temperature variations, further highlighting the potential of fungal pigments as environmentally friendly alternatives to conventional dyes.

yellow and red pigments which can be able to dissolve in water have high attraction to wool fibers have been identified by researchers and are suitable for industrial applications due to their stability across various temperatures and pH levels (9). Additionally, *Penicillium species* produce ankaflavin, a Monascus pigment that binds well to wool fibers, and Several species of *Penicillium* from Amazonian soil produce particularly vibrant pigments suitable for textile applications (10). Additionally, pigments like xylindein, draconin red, and yellow pigment derived from rotting hardwood logs in Canada were successfully applied to dye strips of various fabrics (11).

Cosmetic Industries

With the growing demand for natural products, cosmetic industries are increasingly turning to alternatives to synthetic pigments, and fungal pigments have garnered significant attention for their various benefits. Melanin, carotenoids, and lycopene are pigments that have shown promise for cosmetic applications, Notably, pigments from fungi such as *Monascus* and similar varieties have already made their way into the market, finding applications in products like skin conditioners, skincare items, and lipsticks (12).

Melanin acts as a natural "sunscreen" by absorbing a wide range of UV and visible light wavelengths. In addition to its UV protection, melanin serves as a potent antioxidant and is commonly found in dermal and cosmetic products like sunscreens and hair dyes. Furthermore, despite the wealth of research demonstrating its potential currently, the majority of melanin-based applications are still under development and have yet to be commercialized. As industries shift toward more sustainable materials, the research on microbial melanin remains an area with significant untapped potential for future innovation.

Food Industries

Much of the research on fungal pigments has focused on their application as food colorants, with this paper emphasizing their potential in various industries, particularly the food sector. Examples include *Monascus* pigments, arpink red, and β -carotene which are already present in market as edible dye (13).

Monascus, a genus frequently employed as a food coloring agent, is widely utilized in Asian culinary traditions. The pigments typically include six main azaphilone pigments which have shows different colors. Nevertheless, specific strains of species may produce citrinin, a mycotoxin with established nephrotoxic and hepatotoxic side-effects on people (14). Consequently, food colorants derived from this genus are prohibited in the western

countries, fuelling ongoing debates regarding their safety in food items. In contrast, melanin has been explored for eco-friendly applications, for instance, in the creation of silver nanostructures known for their broad-spectrum antimicrobial effects against pathogens found in food, presenting promise for both the food and health industries.

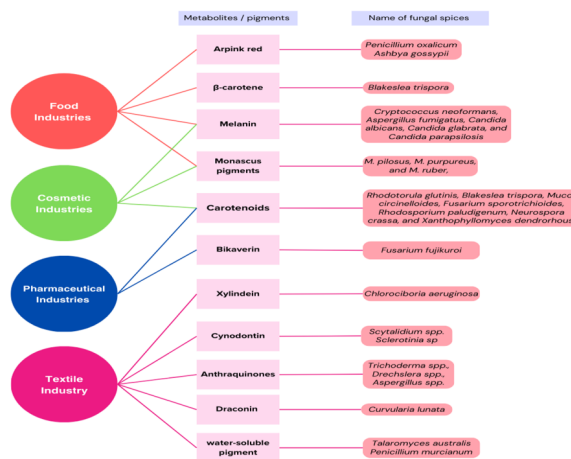
Pharmaceutical Industries

The pharmaceutical industry has recognized the significant potential of fungal pigments. One example is bikaverin, a vivid red pigment classified as a naphthoquinone, primarily occurring in the genus *Fusarium*. A polyketide biosynthetic pathway is responsible for the synthesis of bikaverin. This pigment is highly regarded for its bioactive properties and its application as a colorant in textiles. Bikaverin exhibits broad bioactivity, including antimicrobial and anti-proliferative effects. This makes it a strong contender for use in pharmaceutical research and different industrial applications (15).

Carotenoids, another class of fungal pigments, also hold a prominent role in the pharmaceutical field, particularly in combating respiratory diseases, ocular complications, chronic illnesses, and neurodegenerative disorders(20). Their immune-boosting properties are largely due to their antioxidant capabilities, they provide protection against cancers in humans and animals through the neutralization of ROS. Serving as precursors to vitamin A, carotenoids act as bioactive compounds that contribute to lowering the chances of degenerative diseases.

These pigments offer promising avenues for further exploration in both pharmaceutical and industrial sectors, with the potential to contribute to sustainable health solutions.

BIOACTIVE PROPERTIES -Several studies have highlighted the health benefits of fungal pigments over synthetic alternatives, Specifically, they exhibit antibacterial properties against a range of harmful yeast bacteria and fungi. It has been suggested by researchers that these bioactive pigments have potential applications as



pigments to manufacture medical items such as suture threads, bandages, and face masks, with promising results indicating the feasibility of such applications (16). For instance, *Aspergillus* produces neoaspergilliac acid, which exhibits antibacterial activity against bacteria, as well as antifungal action against *Candida* (17).

Fungal pigments have demonstrated anticancer and anti-tumor properties, with multiple studies suggesting their potential use as anticancer agents. For instance, pigments derived from *Monascus* species have shown significant anticancer activity against various types of cancer, (18). Another study found that melanin from *Phoma* sp. RDSE17, at a concentration of 80 µg/mL, inhibited the growth of human lung cancer cells (19).

In a recent study evaluating the dermal toxicity of pigments fungi in Wistar rats has confirmed that fungal pigments are nontoxic in nature, proposing their promising application in cosmetics and textile dyeing industries, furthermore the antioxidant properties of microbial pigments, like violacein, naphthoquinones and carotenoids from various fungi (16), have been the subject of extensive research. These findings suggest that fungal pigments hold great promise for applications in the healthcare industry.

CONCLUSION-In conclusion, fungal pigments present a potential substitute to synthetic dyes and colorants across different industries. The range of bioactive properties they possess, from antimicrobial to antioxidant and anticancer activities, highlights their potential for sustainable purposes. Fungal-derived pigments can mimic the vibrant hues of artificial dyes in the textile industry while providing environmental advantages. The cosmetic sector is increasingly recognizing the advantages of natural pigments like melanin and carotenoids, which provide UV protection and antioxidant benefits. In food industries, while some fungal pigments face regulatory challenges due to safety concerns, their applications as natural colorants remain significant. Additionally, the pharmaceutical

potential of fungal pigments, particularly in producing bioactive compounds like biliverdin and carotenoids, underscores their relevance in health and wellness. As research progresses, fungal pigments are going to play a crucial part in promoting sustainable practices and innovations in these industries.

REFERENCES

- Watts, I., Chazan, M., & Wilkins, J. (2016). Early evidence for brilliant ritualized display: Specularite use in the Northern Cape (South Africa) between ~ 500 and ~ 300 ka. *Current Anthropology*, 57(3), 287-310.
- Banc, R., Filip, L., Cozma-Petruț, A., Ciobarca, D., & Miere, D. (2024). Yellow and Red Synthetic Food Dyes and Potential Health Hazards: A Mini Review. *Bull. Univ. Agric. Sci. Vet. Med. Cluj-Napoca. Food Sci. Technol*, 81, 1-17.
- Lin, L., & Xu, J. (2022). Production of fungal pigments: Molecular processes and their applications. *Journal of Fungi*, 9(1), 44.
- Afroz Toma, M., Rahman, M. H., Rahman, M. S., Arif, M., Nazir, K. N. H., & Dufossé, L. (2023). Fungal pigments: Carotenoids, riboflavin, and polyketides with diverse applications. *Journal of Fungi*, 9(4), 454.
- Kirti, K., Amita, S., Priti, S., Mukesh Kumar, A., & Jyoti, S. (2014). Colorful world of microbes: carotenoids and their applications. *Advances in Biology*, 2014(1), 837891.
- Garcia-Rubio, R., de Oliveira, H. C., Rivera, J., & Trevijano-Contador, N. (2020). The fungal cell wall: *Candida*, *Cryptococcus*, and *Aspergillus* species. *Frontiers in microbiology*, 10, 2993.
- Lin, L., & Xu, J. (2022). Production of fungal pigments: Molecular processes and their applications. *Journal of Fungi*, 9(1), 44.
- Gomes, D. C. (2024). Fungal Pigments: Applications and Their Medicinal Potential. In *Fungi Bioactive Metabolites: Integration of Pharmaceutical Applications* (pp. 651-681). Singapore: Springer Nature Singapore.
- Hernández, V. A., Galleguillos, F., Thibaut, R., & Müller, A. (2019). Fungal dyes for textile applications: testing of industrial conditions for wool fabrics dyeing. *The Journal of the Textile Institute*, 110(1), 61-66.
- Kalra, R., Conlan, X. A., & Goel, M. (2020). Fungi as a potential source of pigments: harnessing filamentous fungi. *Frontiers in Chemistry*, 8, 369.
- Hinsch, E. M. (2018). Oils Colored with Wood-Staining Fungal Pigments: Color Loss, Oxidation, and Structural Breakdown.
- Saravanan, T. S., Gopikrishnan, V., Manikkam, R., Kaari, M., Annamalai, K. K., Song, J., & Soyong, K. (2024). Translational Value of Natural Pigments with Reference to Healthcare and Cosmetic Applications. In *Translational Research in Biomedical Sciences: Recent Progress and Future Prospects* (pp. 235-250). Singapore: Springer Nature Singapore.
- Dufossé, L. (2018). Red colourants from filamentous fungi: are they ready for the food industry?. *Journal of Food Composition and Analysis*, 69, 156-161.
- Lee, C. H., Lee, C. L., & Pan, T. M. (2010). A 90-D toxicity study of *Monascus*-fermented products including high citrinin level. *Journal of food science*, 75(5), T91-T97.
- Stępień, Ł., Lalak-Kańczugowska, J., Witaszak, N., & Urbaniak, M. (2020). *Fusarium* secondary metabolism biosynthetic pathways: so close but so far away. *Co-evolution of secondary metabolites*, 211-247.
- Lagashetti, A. C., Dufossé, L., Singh, S. K., & Singh, P. N. (2019). Fungal pigments and their prospects in different industries. *Microorganisms*, 7(12), 604.
- Aspergillus sclerotiorum* DPUA 585 produces neoaspergilliac acid, which exhibits antibacterial activity against *Escherichia coli*, *Mycobacterium smegmatis*, and *Staphylococcus aureus*, as well as antifungal action against *Candida albicans*
- Elkhateeb, W., & Daba, G. (2023). Fungal Pigments: Their Diversity, Chemistry, Food and Non-Food Applications. *Applied Microbiology*, 3 (3), 735-751.
- Surendirakumar, K., Pandey, R. R., Muthukumar, T., Sathiyaseelan, A., Loushambam, S., & Seth, A. (2022). Characterization and biological activities of melanin pigment from root endophytic fungus, *Phoma* sp. RDSE17. *Archives of Microbiology*, 204(3), 171.
- Metibemu, D. S., & Ogungbe, I. V. (2022). Carotenoids in drug discovery and medicine: pathways and molecular targets implicated in human diseases. *Molecules*, 27(18), 6005.

BIOACTIVE PROPERTIES

