REVIEW ARTICLE

The Use of Biological Pigments in Cosmetics for Eco-friendly and Sustainable Coloring

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ABSTRACT

Synthetic pigments have been used in the cosmetics industry for a very long time in everything from lipsticks to eye shadows. However, the hunt for sustainable and secure alternatives is driven by escalating environmental and health concerns. A feasible alternative that offers benefits in terms of biodegradability, sustainability, and safety is bacteria-based pigments. The potential of bacterial pigments in cosmetics is explored in this review article by focusing on their sources, extraction processes, and advantages over synthetic alternatives. The study also explores the safety and regulatory framework pertaining to bacterial pigments and presents actual case studies of their successful application in cosmetic products. A scenario on the potential impact of bacterial pigments on the cosmetics market is provided as a conclusion. The demand for various cosmetics is on rise and ever-increasing due to the inherent desire to look beautiful. A marked increase in women's use of different cosmetic formulations has been witnessed in recent years. Varieties of cosmetics from different manufacturers are available in the market. Synthetic colors have been used in cosmetics for a long time, resulting in human health risks and environmental pollution. Therefore it is critical to search for novel natural pigments that are safe and alternative to synthetic ones. Compared to synthetic colors, microbial pigments show better biodegradability and greater compatibility with the environment.

Keywords: Bacterial pigments, Cosmetics, Sustainability, Biodegradability, Safety.

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INTRODUCTION

The cosmetics sector, worth several billion dollars and still expanding, includes a wide range of goods, from cosmetics and skincare to hair and body care. This industry depends heavily on color, which frequently acts as the distinctive element that draws customers in and heightens aesthetic appeal.[1] The color palette of cosmetics has traditionally been created using synthetic pigments and dyes, which, while effective, have drawn criticism for their potential negative effects on the environment and human health.[2] The search for new sources of pigments that are not only brilliant but also environmentally beneficial has been prompted by the contemporary era, which is characterized by a greater awareness of sustainability.[3]

A class of bio-based colorants called bacterial pigments has showed a lot of promise as a sustainable substitute for synthetic substances.[4] These pigments, which are derived from microorganisms, provide a variety of advantages, from a smaller environmental impact to enhanced safety profiles.[5] To fully comprehend the potential and restrictions of using bacterial pigments in cosmetics. However, more in-depth study and discussion are needed.[6]

This review seeks to clarify the function of bacterial pigments as a green coloring choice in the cosmetics sector. It will give an overview of the types and sources of bacterial pigments, discuss their benefits and drawbacks, scrutinize the safety and regulatory environment, and look at case studies of successful applications.[7,8] Finally, the prospects and challenges for bacterial pigments in cosmetics lie ahead. This thorough analysis will serve as a resource for researchers, formulators of cosmetics, and other industry participants to explore bacterial pigments as a suitable alternative in cosmetic

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products. Demand for cosmetic and personal care products has grown substantially due to increased income levels, changing lifestyles and urbanization. The new generation is experiencing a changing standard of living, which creates a vast demand for cosmetics. Increasing financial independence of women has resulted in increased inclination towards color cosmetic products. Changes in the lifestyle of the rural population and the impact of Western culture are also boosting the growth of the cosmetics market globally. India's cosmetic market is expected to reach $20 billion by 2025 and India will be the largest consumer with a 5% market share in the global beauty sector.[9,10]

Importance of Color in Cosmetics

Color offers value and functionality to cosmetic products beyond just being a decorative feature. These products' aesthetic appeal is improved via the thoughtful use of color, which also influences consumer behavior and shapes brand identification. Here, we look at the numerous functions that color performs in the cosmetics sector, highlighting how essential it is.

Emotional and Psychological Impact

Colors have the power to arouse various feelings and psychological reactions. For instance, the colors red and blue may conjure up different emotions depending on how they are used. Cosmetics businesses use these emotional triggers as inspiration for goods that target a certain market or emotional state.

Enhancement of Natural Features

Natural traits are frequently emphasized and improved with cosmetics. The appropriate colors can give the appearance of larger lips, deeper eyes, and a healthy glow on the skin. It's critical for cosmetic companies to provide a wide choice of hues that appeal to various skin tones and individual preferences because poorly picked colors can have the opposite impact.

Trend-Setting

Seasonal color trends have a big impact on the cosmetics business. Based on these trends, businesses frequently produce limited-edition shades or collections that increase consumer enthusiasm and boost sales.

Corporate Identity

Establishing and maintaining brand identification requires the use of color. A product's marketability can be increased by using distinctive colors or tints on its packaging. It's common to recognize iconic products just by their color, such as certain brands of red lipstick or a specific eyeshadow hue.

Quality Perception

Cosmetic goods' color constancy and payoff are regarded as quality indicators. A foundation that offers even coverage in a natural shade or a lipstick that keeps its color during use can increase customer confidence and foster brand loyalty.

Formulation Obstacles

The significance of color also poses difficulties for formulation. For application on human skin, pigments must be stable, non-reactive, and secure. They should also be environmentally friendly and sustainable without sacrificing their vibrancy or longevity.

Color plays a variety of roles in the cosmetics industry, impacting not only the aesthetic appeal but also the usefulness, emotional response, and even perceived product quality. The emphasis is gradually shifting towards natural and environmentally friendly colors as sustainability emerges as a crucial issue. In this regard, bacterial pigments present a viable substitute that could completely transform the cosmetics industry's use of color.[11,12]

Natural *vs.* Synthetic Pigments

Over time, the selection of pigments for cosmetic goods has changed, balancing elements including vibrancy, stability, and safety. However, the argument between synthetic and natural pigments is becoming more significant as customer preferences shift towards natural and environmentally friendly products. This section gives a general review of the synthetic pigments now used in cosmetics, explores their disadvantages, and introduces natural substitutes, with a focus on bacterial pigments.

Current Synthetic Pigments

Because of their vibrant colors, stability, and affordability, synthetic pigments, including carbon black, titanium dioxide, and different iron oxides, are frequently used in cosmetics. These pigments are frequently used in foundation, eyeshadow, lipstick, and nail polish.

- Carbon black is used in mascara and eyeliners for a deep black shade.
- Due to its ability to whiten skin and filter UV rays, titanium dioxide is frequently included in foundations and sunscreens.
- Iron oxides: These are used to add earth tones to a variety of cosmetics, including bronzers and eyeshadows.

Drawbacks of Synthetic Pigments

Environmental impact

The procedures used to create these pigments are frequently hazardous to the environment, increasing waste and pollution.

Potential health risks

Unfavourable effects on health have been linked to some synthetic colors. For instance, some red dyes have the potential to cause allergic reactions.

Regulatory obstacles

As a result of the aforementioned issues, synthetic pigments frequently have to pass severe testing procedures before they can be used in cosmetics.

Consumer perception

Today's consumers are more knowledgeable about the contents in the items they buy, and they frequently hold synthetic compounds in low regard.

A Brief Introduction to Natural Remedies

A rising number of people are interested in finding natural alternatives that are strong, sturdy, environmentally friendly, and safe to use in light of these shortcomings.

- Plant-based pigments, including chlorophyll or beetroot extract, are being used more frequently in cosmetics.
- Similar to mica, mineral pigments have been employed as natural colorants, albeit their supply can occasionally give rise to ethical questions.

Bacterial Pigments

An emerging star in this field, bacterial pigments such as carotenoids, violacein, and indigo offer a variety of hues and are biodegradable, possibly making them the natural coloring of the future for cosmetics.

The shift to natural substitutes, particularly bacterial pigments, denotes a move towards more environmentally and health-conscious decisions. In the sections that follow, we'll delve more deeply into bacterial pigments and examine how they can represent the next step in environmentally responsible cosmetic coloring.

What are Bacterial Pigments

Researchers have been investigating numerous natural sources, including bacteria, in their search for environmentally acceptable and sustainable pigments for the cosmetics sector. In addition to serving several purposes in microbial physiology, bacterial pigments are organic chemicals made by bacteria that come in various hues, from yellows and reds to blues and purples. In order to comprehend their possible uses in cosmetics, this section tries to define bacterial pigments and investigate their types.[13-17] Bacterial cells produce secondary compounds known as bacterial pigments as they proliferate. These substances perform a number of different tasks, including UV protection, free radical scavenging, and even acting as antibiotics against competing microbes. They are frequently caused of distinctive colors seen in bacterial colonies. Bacterial pigments have drawn attention for their potential in a number of uses, including as natural colorants in cosmetics, because of their bioactive qualities and stability.

Types of Bacterial Pigments

An overview of some bacterial pigments with particular relevance to the cosmetics sector is summarized in Table 1:

Table 2 lists bacterial pigments used in a range of pharmaceutical products.

Sources of Bacterial Pigments

The potential of bacterial pigments as sustainable colorants in the cosmetics industry is gaining recognition, but an essential part of harnessing this potential lies in understanding their sources. This section explores different environments and

Table 1: Bacterial pigments relevant to the cosmetics industry

S. No.	*Type of pigment*	*Producing bacteria*	*Color range*	*Notable properties*	*Applications in cosmetics*
1	Carotenoids	*Actinobacteria, Flavobacterium*	Yellow to red	Antioxidant	Colorant, antioxidant
2	Violacein	*Chromobacterium violaceum*	Blue to purple	Antimicrobial	Colorant, antimicrobial
3	Prodigiosin	*Serratia marcescens*	Red	Antimicrobial, immunosuppressant	Colorant, potential antimicrobial, immunosuppressant
4	Indigo	*Pseudomonas*	Deep blue	Historical significance in textile dyeing	Colorant
5	Melanins	Various	Brown to black	Protection against radiation and reactive oxygen species	Colorant, protective
6	Phycoerythrins	*Cyanobacteria*	Red	Fluorescent labeling	Colorant, fluorescent labeling
7	Pyocyanins	*Pseudomonas aeruginosa*	Blue to green	Antimicrobial	Colorant, potential antimicrobial

Table 2: Bacterial pigments with various pharmaceutical applications:

S. No.	*Pigment*	*Clinical uses*	*Color*	*Microorganisms*
1	Astaxanthin	Antioxidant, photo-protectant, anti-cancer, anti-inflammatory	Red to orange	*Agrobacterium aurantiacum, Paracoccus carotinifaciens*
2	β-Carotene	Anticancer, antioxidant	Red	*Rhodococcus maris, Rhodococcus ruber*
3	Canthaxanthin	Antioxidant, photoprotectant, anti-cancer, anti-inflammatory	Orange to deep pink	*Bradyrhizobium spp., Lactobacillus pluvialis*
4	Deinoxanthin	Anti-cancer	Red	*Deinococcus radiodurans*
5	HeptylProdigiosin	Antiplasmodial	Red	*α-Proteobacteria*
6	Prodigiosin	Anti-cancer, DNA cleavage, immunosuppressant	Red	*Serratia marcescens*
7	Pycocyanin	Cytotoxicity, neutrophil apoptosis, ciliarydysmotility, proinflammatory	Blue	*Pseudomonas spp.*
8	Staphyloxanthin	Antioxidant	Yellow	*Staphylococcus aureus*
9	Undecylprodigiosin	Antimalarial activity, antibacterial, antioxidant, anti-cancer	Red	*Streptomyces sp.*
10	Violacein	Antifungal, antibacterial, antiplasmodial, anti-cancer	Purple	*Chromobacterium violaceum, Collimonas sp., Duganella sp., Pseudoalteromonas sp.*

Table 3: Sources and characteristics of bacterial pigments across different environments[18]

Category	*Source type*	*Examples of bacteria*	*Pigments produced*	*Notes*
Terrestrial sources	Soil bacteria	*Actinobacteria*	Carotenoids	Common soil inhabitant known for antioxidant pigment production
	Plant-associated bacteria	*Serratia marcescens*	Prodigiosin	Lives symbiotically with plants, known for red pigment production
Aquatic Sources	Marine bacteria	*Chromobacterium violaceum*	Violacein	Found in marine environments, produces blue to purple pigments
	Freshwater bacteria	*Cyanobacteria*	Phycoerythrins	Common in lakes and ponds, produces red pigments
Extreme Environments	Thermal vents and hot springs	Extremophilic Bacteria	Various Stable Pigments	Capable of surviving in high-temperature environments
	Acidic and alkaline lakes	Extremophilic Bacteria	Unique Pigments	Thrives in extreme pH conditions, produces pH-stable pigments
Endophytes and Pathogens	Endophytes	Various	Various	Lives inside plants, may produce pigments that aid in plant-bacteria interactions
	Pathogenic Bacteria	*Pseudomonas aeruginosa*	Pyocyanins	Less desirable due to safety concerns, produces blue to green pigments
Fermentation	Industrial Production	Cultured Bacterial Strains	Various	Employed for rapid, large-scale extraction in controlled environments

organisms listed in Table 3 from which these vibrant pigments can be sourced, detailing their origins and how they are obtained.

Advantages of Bacterial Pigments

Bacterial pigments have become a possible replacement for conventional synthetic colorants as the cosmetics industry strives to be environmentally friendly and sustainable. The main benefits of bacterial pigments are discussed in this section, emphasizing the sustainability, biodegradability, and safety features that make them ideal for cosmetic applications.[19]

Sustainability

Low environmental impact

Bacterial pigments can be manufactured with little environmental impact, unlike synthetic pigments, whose manufacture frequently calls for toxic chemicals and produces large waste.

Bacteria are a renewable resource because they can multiply quickly in regulated environments. This guarantees a steady and long-lasting supply of pigments.

Energy efficiency

Compared to the energy-intensive methods needed to create synthetic pigments, the energy cost of creating bacterial pigments through fermentation is typically economical.

Biodegradability

Eco-friendly disposal

The biodegradability of bacterial pigments is one of their strongest benefits. Because they are natural products, pollution issues can be reduced by the ability of other environmental microbes to break them down.

Reduced accumulation

Synthetic pigments can build up in the environment and cause risks over time. Bacterial pigments are more environmentally friendly because they don't accumulate because of their biodegradable nature.

Green standards compliance

The biodegradable property of bacterial pigments fits in well with the regulatory focus on sustainable and green cosmetics that is becoming more and more prevalent, giving them a competitive advantage in the market.

Safety

Non-toxic

The majority of bacterial pigments are non-toxic and present negligible health hazards, particularly when derived from bacterial strains that are not pathogenic.

Skin-friendly

As a result of their natural origins and generally non-toxic makeup, bacterial pigments are frequently more skin-friendly than synthetic equivalents that could irritate or cause allergies.

Some bacterial pigments give more than simply color; they also have health advantages. For instance, violacein exhibits antibacterial action, while carotenoids have antioxidant characteristics, giving functional advantages to their use in cosmetics.[20-25]

Bacterial Pigment Extraction and Processing

Bacterial pigments must first be effectively isolated and processed before they can be transferred from microbial cells into cosmetics goods. This step is crucial since it influences the yield as well as the purity and usefulness of the pigments.

This section covers numerous techniques used to extract and treat bacterial pigments for cosmetic use. Figure 1 depicts a process summary.

Pre-culture Conditions

Culture medium

The choice of medium significantly impacts For optimal yield, nutrient-rich or specialized mediums are frequently used.

Temperature and pH levels must be ideal for the bacteria to produce a a maximum yield of colors.

Extraction Techniques

Pigments are frequently extracted using organic solvents like ethanol, methanol, or acetone. Bacterial cells must first be extracted and then lysed to release the pigments into the solvent.

Mechanical disruption

To rupture bacterial cells and release the pigments, methods like ultrasonification may be used.

Enzymatic lysis

As a softer alternative to mechanical disruption, enzymes can be utilized to selectively rupture bacterial cells.

Purification

In the first phase of purifying extracted pigments using column chromatography, contaminants are separated depending on molecular size or charge.

High-performance liquid chromatography

High-performance liquid chromatography (HPLC) can be used to acquire highly pure pigments for further purification.

Crystallisation

To reach the highest level of purity, the pigments may occasionally be crystallised.

Tests and Quality Assurance

- Spectroscopic analysis is performed to determine the identification and purity of pigments. Techniques employed include UV-vis spectroscopy and mass spectrometry.
- Safety testing: The pigments go through extensive safety testing before being used in cosmetics, including tests for toxicity and skin irritability.

Increased Size and Commercial Processing

Large fermenters are frequently used to cultivate bacteria for large-scale production, after which the pigments are removed and purified.

Continuous cultures

This technique is more effective than batch procedures for some bacterial species because it enables continuous pigment production.

Regulatory and Safety Issues

Despite the fact that bacterial pigments have several benefits, including sustainability and biodegradability, it is crucial

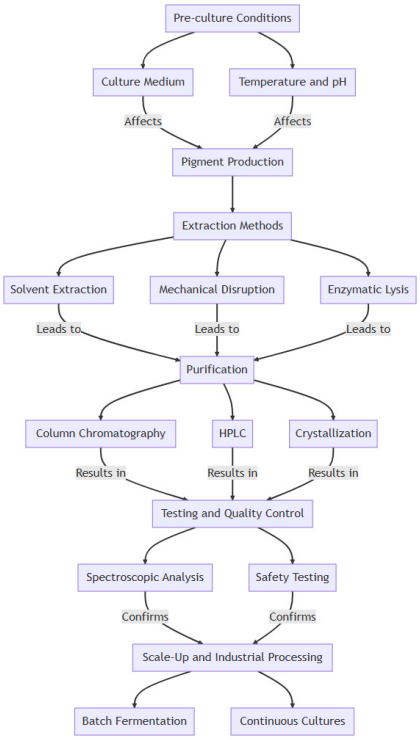

Figure 1: Flow diagram for production of bacterial pigments

to address the safety and legal issues related to their usage in cosmetics. The main safety issues and the regulatory framework governing the use of bacterial pigments in cosmetic products are covered in this section.

Safety Issues

Allergenicity

Bacterial pigments provide the same potential for allergic reactions as any other biological product. Before these pigments can be used in cosmetics, they must pass safety testing for allergenicity.

Toxicity

Although most bacterial pigments are non-toxic, thorough toxicological studies and skin and eye irritation tests are frequently necessary.

Purity

Impurities such as lingering solvents or bacterial parts may be dangerous. The extraction and purification operations must meet high purity standards.

Pathogenicity

Pathogenic microorganisms create certain colors. Even though the pigments themselves are benign, there is a chance that they could become contaminated with other harmful substances.

Regulatory Environment

FDA guidelines

The Food and Drug Administration (FDA) in the United States controls the use of colorants in cosmetics. Any new pigment,

whether made from bacteria or not, must adhere to the exacting standards established by the FDA.

EU regulations

In Europe, the safety of cosmetic products, including pigments, is regulated by the European Medicines Agency (EMA) and the European Chemicals Agency (ECHA). Any new pigment must first receive approval before it can be sold.

Standards set by the International Organisation for Standardisation (ISO)

These standards, particularly ISO 22716, which details good manufacturing practices for cosmetics, may also be used.

Natural and organic certifications

In Europe, certifications like ECOCERT or COSMOS give consumers assurance about the product's natural or organic origins. Bacterial pigments must adhere to strict standards to be used in products labeled as natural or organic.

Local regulations

It's crucial to take into account country-specific laws, particularly for markets like China or India where cosmetic laws might vary greatly from those in the West.

Ethics-Related Matters

Animal testing

Alternative approaches must be taken into account when assessing the safety of bacterial pigments because the cosmetics industry is moving away from using animals in testing.

Transparency

It may be required by certain legislation and is regarded as best practice to fully disclose the source of the pigment, the methods used to prepare it, and any genetic change of the bacterial strains.[26-33]

Future Perspectives and Conclusion

The switch from conventional synthetic colors to more environmentally friendly and long-lasting substitutes, such as bacterial pigments, has begun to pick up steam. Bacterial pigments offer a workable alternative as the cosmetics sector struggles with greater scrutiny on environmental sustainability, safety, and ethical considerations. This section summarises the main ideas presented in this review and offers an outlook on the future use of bacterial pigments in cosmetics.

Future Perspectives

Technological developments

We can anticipate increasingly effective and affordable ways to extract and purify bacterial pigments as biotechnology techniques improve. Methods like metabolic engineering could provide higher yields and even novel color variations.

Regulatory evolution

Regulatory processes are expected to become more simplified as more information about the security and effectiveness of bacterial pigments accumulate, making it simpler for businesses to use these natural colorants.

Consumer awareness

The market will likely be driven towards natural alternatives like bacterial pigments as educated consumers demand transparency and sustainability.

Functional benefits

Studies into the potential health advantages of specific bacterial pigments, such as their antioxidant or antibacterial capabilities. These features might set bacterial pigments apart from their synthetic competitors.

Worldwide commercial

As nations update their cosmetics laws to place a higher priority on safety and environmental impact, bacterial pigments may become acceptable ingredients on a worldwide scale, which would increase their commercial reach.

Customization and personalization

Data analytics and microbiology development may lead to the development of personalized cosmetic products with bacterial pigments catered to different skin types and preferences.[34]

CONCLUSION

Particularly in the context of a world that is becoming more environmentally conscious, bacterial pigments present an appealing alternative to synthetic colors. Beyond color, their benefits include aspects like sustainability, biodegradability, and even additional health perks. Despite the difficulties, notably in the areas of extraction effectiveness, purity, regulatory compliance, and consumer acceptance, continuous research and successful case studies indicate a bright future. The cosmetics sector is at a turning point where conventional methods are challenged and new approaches are sought. Bacterial pigments have the ability to revolutionize the industry by addressing both ethical and market trends. Given the trajectory of recent breakthroughs, their increasing integration in cosmetics is not just a potential but also appears to be an impending reality. The cosmetics industry has a rare chance to use bacterial pigments to improve sustainability and consumer friendliness while broadening the range of choices available to both formulators and end users.

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