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REVIEW ARTICLE

BRIEF REVIEW ON MICROBIAL PIGMENTS AND THEIR PROSPECTS

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Abstract

The large number of microorganisms present in nature, as well as their ease of cultivation, contributes to the advantage in the extraction and manufacture of natural colours or pigments. Microbial pigments are classified as secondary metabolites and are mostly formed owing to poor metabolism during stressful situations. These microbial pigments are safe for human use, have increased biodegradability, and are more environmentally friendly, making them suitable for a variety of applications in the pharmaceutical, textile, cosmetic and food sectors. The therapeutic character of bacterial pigments is demonstrated by their antibacterial, anticancer, cytotoxic and outstanding antioxidant activities. Identifying novel microbiological sources and improving process parameters are two areas of focus for affordable pigment production. This also suggests that future generations will rely on microbial pigments rather than manmade colorants for a sustainable lifestyle. This article has attempted to take a brief idea on microbial pigments and their prospects in different sectors.

Introduction:-

As the world's current trend turns to the usage of ecologically friendly and biodegradable products, the demand for natural dyes is rising by the day (1). Synthetic and natural dyes continue to be widely employed in a variety of sectors, including food manufacturing, textiles, paper manufacture and agricultural operations (2). However, people are seeking for more natural items, such as synthetic substances, due to their carcinogenicity and the consequences of their leftovers on the ecosystem, and certain synthetic colours are now forbidden (3). The industry is migrating from natural sources to the creation of pigments and products containing natural chemicals are increasing in market value (4). Microbial communities have enormous potential for producing unique and intriguing aesthetic characteristics. One of these advantages is the generation of pigments by various microorganisms, which has been established in recent years (5). Different species of microbes synthesize these colours as secondary metabolites, and they are uncommon in all forms (6). This provides an advantage since they can easily grow on inexpensive substrates under regulated settings. Furthermore, biopigments formed from microbes are superior to plants because of their stability and availability for cultivation throughout the year (7).

Microorganisms employed to generate pigments must fulfill a number of requirements, including the capacity to use a diverse spectrum. Carbon and nitrogen supplies, endurance to pH and temperature, high mineral content concentration, moderate growing circumstances, fair colour production, minimal toxicity or pathogenecity and facile

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separation of cell mass (5). Therefore, the production of microbial pigments is an evolving field of research, currently revealing its potential in various industrial applications.

History

A evolutionary history of pigment producing microbes:-

In 1856, Henry Perkin discovered the first synthetic dye, "Mauveine. Since 1884, Monascus pigment has been well-known as a natural colourant worldwide. (8). Monascus sp. was traditionally farmed and utilised in the orient for the production of red rice wine and red Chinese rice (9). Until date, 65 distinct monascus pigmented compounds have been identified, and some of them show antibacterial, anticancer, and anti-obesity actions were recently thoroughly studied. (10). In 1954, the first carotenoid pigments from Cryptococcus were introduced. Ingraham, Baumann, and Valadon identified many carotenoid-producing non-photosynthetic bacteria and fungi between 1934 and 1976 (5). Halobacterium's purple pigment, bacteriorhodopsin, was identified in the early 1970s. (11).

During the late 1970s and early 1980s, Dunaliella salina produced beta-carotene. In 1964, thermorubin, a red pigment, was discovered from a weakly thermophilic soil actinomycetes. Thermoactinomyces antibioticus. (12).

Ecological and habitat of pigmented microorganisms

Microbes produce pigments to assist them live in difficult environments, such as extremely high or extremely low temperatures. It mostly occurs within the cytoplasm in response to extreme environmental circumstances. (13). That’s why these coloured bacteria are spread in varied geographical situations, from arctic regions to tropical environments, and from airborne to deep-sea areas. Many bacteria and fungi that live in cryospheric environments generate a range of colours; these microorganisms are also known as cold-adapted microbes. It has been observed that a wide range of coloured molecules produced by microbes may be found in glaciers, ice cores, and sea surface waters, demonstrating that pigment creation is required for microorganisms to adapt to that specific environment (or cryosphere). Arthrobacter, for example, creates a Caretenoid pigment that stabilizes the cell membrane of bacteria and allows them to adapt to the cryosphere (14, 15, 16). These tactics avoid much harm, such as photodamage, suppression of metabolic processes, and cellular repair mechanisms. (Mueller et al. 2005). Some microorganisms adapt to their habitat, such as bacteria from terrestrial conditions that reach marine conditions via discharge from hospitals and home sewages, allowing them to adapt to a new environment. Marine pigmented microorganisms are garnering more attention than the terrestrial environment, since they produce a variety of bioactive pigment molecules.

Extreme environmental circumstances in marine, such as absence of light, high salinity, high pressure and low temperature, leads to the synthesis of unique compounds. A red pigment producer, Talaromyces albobiverticillius 30548, was identified from silt collected on Reunion Island (Indian Ocean). Some sessile and non-sessile invertebrates, such as corals, sponges, and squirts, are exceptionally vivid in colour due of photosynthetic pigments of symbiotic bacteria present. (17). In a recent study, Fouillaud and her team isolated 42 coloured compounds from different samples (coral rubble and living coral from underwater volcano slopes, hard substrates, open water, and sediments) that belong to the genera Aspergillus, Penicillium, and Talaromyces in the family Trichocomaceae. (18 Alternaria sp. (found in the soft coral of the South China Sea) generates a red and yellow pigment, which is another method of acquiring a broad spectrum of colours from invertebrate-inhabiting fungi (19).

Many fungi are suited to high salt concentrations, i.e. Halophilic fungal isolates from the eastern shore of the Adriatic sea, such as a fungal strain Trimmatostroma salinum and Phaeotheca triangularisp generate melanin pigments (20). Terrestrial soil favors the growth of filamentous fungus due to a reduced degree of mechanical disturbance and a suitable source of getting fungal pigment. For example, Penicillium purpurogenum DPUA 1275 generates yellow and red colour. (from soil sample) (21), Penicillium purpurogenum rubisclerotium and Fusarium oxysporum produces red pigment (22). Lichens, such as Trypethelium eluteriae (yellow pigment) and Trypethelonamide (new dark violet red pigment), are another source of fungal pigment. (23). In a recent investigation, populations of coloured bacteria were identified from caves (24). Pigmented bacteria may be isolated from many marine environments, such as saltwater, marine sediment, seagrass, sponge, mussel, and sea cucumber. (25). The red pigment 'Prodiogiosin' was isolated from sea sponges that are symbiotically connected with microorganisms (26). These bacterial pigments can also adapt to oil-contaminated soil, nonsaline alkaline groundwater, and ice seas. (e.g. Algoriphagus) (27). Aside from bacteria and fungus, many species of microalgae are spread in diverse settings, which are studied by many scholars. (5).

Pigment production

Pigment production is one of the charismatic traits of microbes (5). These pigments are synthesized by certain microorganisms as secondary metabolites, which are involved in giving protection against UV radiation, increasing resilience to oxidative stress, and occasionally acting as a virulence factor (28).

Carotenoids, flavonoids, tetrapyrroles and some xanthophylls as astaxanthin are most significant natural pigments. Beta carotene is mostly used by industries (29). Carotenoids are produces by plants, algae, yeast, fungi and some bacteria and provide protection from photodamage (30). A large number of bacteria, molds, and yeast algae produce pigments.

Fungal pigments

Fungi have been proved to be an excellent and easily accessible alternative source of natural colours (31). Filamentous fungus have been employed for the commercial manufacture of antibiotics, enzymes, and feed products, among others. These filamentous fungus generate an astonishing diversity of colours, such as carotenoids, melanins, flavins, phenazines, quinones, monascins, violacein & indigo (32).

Monascus pigments have antibacterial, anticancer, anti-mutagenic & anti-obesity effects. The manufacture of red mould rice (ang-kak) using Monascus pigments is the oldest reported usage of fungal colours by humans (32). In comparison to plants, fungi offer more benefits, such as easy and quick growth in a cheap culture media, season-independent pigment synthesis, soluble pigment, stability, and generation of pigment with diverse colour shades (33).

Bacterial Pigments:

Bacteria have a short life, thus the pigment derived from bacteria is superior to other microorganisms. Like fungi, bacteria also produce pigments in wide range like carotenoids, melanin, violacein, prodigiosin, pyocyanin, actinorhodin & zeaxanthin (34). Pigment-producing bacteria are easily isolated from a variety of natural sources, including soil, rhizosphere soil, desert sand, fresh water, and marine samples. These coloured bacteria have been observed in both high and low temperature locations (35). Some bacteria create colours in a broad range, like Streptomyces, Nocardia, Micromonospora, Thermomonospora, Actinoplanes, Microbispora, Streptosporangium, Actinomadura, Rhodococcus & Kitasatospora (36).

Yeast pigments

Aside from bacteria and fungi, yeast has also demonstrated their potential to produce significant levels of carotenoid on low-cost substrates. Asthaxanthin, a carotenoid pigment produced by Xanthophyllomyces dendrohus, is a natural pigment used to colour salmon, lobsters, and egg yolk in poultry. Asthaxanthin has antioxidant properties and is extensively employed in the pharmaceutical, cosmetic, and food sectors (37).

Potential of Microbial Pigments

Textile industry

Historically, the textile industry used a large amount of synthetic colours. These synthetic dyes have been replaced by natural dyes because 15% of them leak out during the dyeing process, and unfortunately, a significant portion of these colours escape traditional waste water treatment procedures and exist as a toxic pollutant, affecting human and environmental health (38).

The textile industry replaces this synthetic pigment with microbiological pigment. Here are several examples:

1. Violacein extracted from C. violaceum able to dye both natural and synthetic fibres (39)
2. Another vivid red pigment, 'Prodigiosin' from Vibrio sp., is used for dyeing a range of fibres including nylon, acrylics, wool and silk (40).
3. A blue pigment Indigoidine is created by a fungal host. Rhodosporidium toruloides has potential use in dye industry (41).
4. Some microbial pigments display varied colours on the kind of fabric, such as pigment from J. lividum shows dark blue colour on vinylon and nylon, whereas cotton, silk, and wool seem bluish purple colour (42).
5. Similarly, certain microbial pigments indicate their higher dyeing affinity on the kind of fabric, such as Yellow pigment from Thermomyces demonstrated a higher dyeing affinity on silk fabric as compared to other fabric (43).

Food industries

The food industry has been employing synthetic dyes as food colourants. Due to the negative health effects of ingesting synthetic food colourants, they are now adopting natural pigments for colouring. Bacterial carotenoids are used in feed as both provitamins and colouring agents (44).

1. Microbial pigments like β-carotene, riboflavin, and phycocyanin in food serve as antioxidants and preservatives (45).
2. Microbial pigments, including β-carotene from Blakeslea trispora, red pigment from Monascus sp., astaxanthin from Xanthophyllomyces dendrorhous, riboflavin from Ashbya gossypii, and Arpink red™ from Penicillium oxalicum, are used as food supplements to improve quality (46).
3. It was observed that carotenoid pigments are also utilised to colour soft drinks, grilled sausages & baked products (47).
4. Food businesses have effectively utilized bacteria that produce violacein (48).
5. Carotenoid pigments from Haematococcus pluvialis and Phaffia rhodozyma are utilised as food supplements for animals and fish (49).
6. Microalgal-derived pigment has a wider applicability in cosmetics, creams and jelly (50).
7. Canthaxanthin, a microbial pigment, is also utilised in a variety of foods, including confectionery, meat, fish, cheese, beverages, wine, and beer (45).

Biomedical applications

Antimicrobial activity

Microbial resistance to antibiotics is developing day by day, which increases the necessity for innovative antimicrobial medicines.

1. Pigment derived from Micrococcus luteus that demonstrates inhibitory effect against wound pathogens such as Pseudomonas, Klebsiella & Staphylococcus sp. (51).
2. Another pigment carotenoid isolation from Holomonas sp. has antibacterial efficacy against antibiotic resistant S. aureus, Klebsiella sp. & Pseudomonas aeruginosa, as well as ophthalmic S. aureus, Streptococcus pyogens & E. coli (52).
3. C. violaceum ATCC 12472 generates violacein and has antibacterial properties against S. aureus (53).
4. Prodigiosin has remarkable antibacterial action against S. aureus, Candida albicans & E. coli (54).
5. Similarly, various prodiginine compounds shown fungicidal action against fungi such as Penicillium, Aspergillus, Candida and Cryptococcus spp. (55).
6. Pigment violacein is an antiviral useful against poliovirus, herpes simplex virus, and simian rotavirus (56).

Antioxidant activity

Chronic illnesses like diabetes, autoimmune disorder & cancer are caused by free radicals (i.e. oxidative stress) and can be treated using antioxidant compounds (57).

1. Because synthetic antioxidants were found to be toxic, pharmaceutical businesses began using antioxidants derived from microorganisms.
2. Xanthomonanadian, caretenoid, and naphthaquinone are three microbial pigments that have showed antioxidant action (58).
3. Melanin extracted from Streptomyces glaucescens & anthraquinones isolated from endophytic Stemphylium lycopersici also exhibit antioxidant properties (59).
4. Cyanobacteria pigments, including lutein, C-phycocyanin, β-carotene and phycobillioproteins, have antioxidant action (60).

Anticancer activity

Some microbial pigments, for example, can combat a variety of cancers.

1. A red pigment derived from Athrobacter sp. G20 acts as an anticancer agent against the oesophageal cancer cell line. (61).
2. Caretenoid from Kocuria sp. against breast and lung cancer cell lines (62).
3. Black melanin from S. glaucescens has cytotoxic action against the HFB4 skin cancer cell line (63)
4. Violacein induces apoptosis in human breast and colon cancer cells (64).
5. Prodigiosin, a natural substance, is mixed with chemotherapy, such as doxorubicin (Dox), to fight against oral squamous carcinoma cells (65).

Bio- indicators

Microbial pigments also operate as a bio-indicator of the health of both aquatic and terrestrial environments. Bio-indicator bacteria that can check environmental health & disclose the qualitative condition of the ecosystem by modifying their behaviour, i.e. producing pigment, therefore these pigmented microbes may be utilised as a bio-indicator (66). For example, the presence of carotenoids in lichens has been proved to rely on the pollution level in the atmosphere of the surrounding environment, where they exist, by examining the carotenoid component of fungus as an indicator (67). When exposed to heavy metals, certain marine bacteria generate less carotenoid, making them bioindicators for heavy metals (68).

Challenges

Regardless of terrestrial or marine origin, bringing any type of flexible medicinal or nutraceutically essential microbial pigment goods onto the market requires a lot of funding as well as experimental labor. Prior assessment of colour stability under heat, light, pH, agitation, aeration, dissolved oxygen, etc. is the most significant problem to study for diverse biotechnological applications. In addition to the solubility optimization procedure, substantial toxicity investigations and regulatory approval are strongly necessary. Other parameters to consider for the desired productivity of microbial pigments in fermentation features include type of bioreactor and its design, type of fermentation, and physicochemical and biological conditions in the fermentation process. (69). Regardless of how microbial pigments are used, some pigments generated by specific microbes are known to boost pathogenecity and virulence. Pseudomonads generate phenazines, which are known to contribute to pathogenecity. Vibrio campbellii has been observed to generate a brown pigment, perhaps owing to pyomelanin. Serratia marcesens is well-known agent of nosocomial infections of the urinary system and wounds.

Other coloured chemicals, such as golden staphyloxanthin, porphyrin, and granadaene generated by Staphylococcus aureus, Porphyromonas gingivalis, and Streptococcus agalactiae, respectively, are associated to possible virulence roles.

Conclusion:-

Natural colored compounds coming from microbial sources including bacteria, fungus, and microalgae are shown to be more useful than manufactured compounds, especially in terms of their varied spectrum of applicability in numerous sectors. Several pigment microbial species have been described and their biological activities are being examined, such that if more study is conducted, these microbial pigments may be of economic interest.

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