

Abstract

Colors significantly influence consumer choices and the marketability of products. While synthetic colorants are the preferred source, they are increasingly criticized for their adverse environmental and health impacts. In this context, microbial-mediated pigment production offers a promising alternative, with advantages for large-scale production. Microorganisms can produce a wide array of pigments, many of which possess bioactive properties making them highly attractive for future industrial applications. Therefore, the present study focused on the exploration of bioactive properties and potential industrial applications of microbial pigments extracted from *S. marcescens* KEGS1, *K. flava* PUTS1_3, *H. rickii* and *Streptomyces* sp. KRTA_1. The red and yellow pigments of KEGS1, and PUTS1_3 were extracted using the solvent extraction method, while the dark brown pigments of the *H. rickii* and KRTA_1 were precipitated using a modified acid precipitation method. The extracted pigments exhibited high stability under different, pH, light and temperature conditions. Purified pigments underwent different preliminary and instrument-based analyses. According to these data, the red pigment of KEGS1 was identified as prodigiosin, while the yellow pigments of PUTS1_3 were identified as carotenoids, including β -carotene. Both the dark brown pigments from *H. rickii* and KRTA_1 were identified as melanin-like pigments. The standard disk/well diffusion assays revealed the antibacterial properties of red and yellow pigments against Gram positive bacteria and the red pigment exhibited antibacterial activity against the Gram negative *E. coli* as well. The DPPH free radical scavenging assay was conducted to assess the antioxidant potentials and the red, yellow and dark brown pigment of *H. rickii* had IC_{50} values of 77.03 ± 0.83 $\mu\text{g/ml}$, 181.95 ± 4.57 $\mu\text{g/ml}$ and >100 $\mu\text{g/ml}$, respectively. Further, photoprotective ability calculated using the Mansur mathematical equation revealed the impressive SPF values of dark brown pigments with 29.30 ± 0.14 (*H. rickii*), and 19.16 ± 0.01 (*Streptomyces* sp. KRTA_1) at 0.2 mg/ml concentration. Fabric dyeing experiments revealed the distinct dyeing performances of the pigments, with the red and yellow pigments showing good fastness properties to washing and pH stability tests, and antibacterial activity against *S. aureus* and *E. coli*. Fabrics dyed with the dark brown pigments exhibited high UV stability. A mutation study was conducted to understand the ecological advantages of pigment production for survival of microorganisms. Mutants were generated through long-term incubation and UV exposure. A non-pigmented mutant, KEGS1_01, exhibited increased tolerance to stress conditions, while the UV mutant KEGS1_40 showed enhanced motility and biofilm production. Genomic and SNP analysis revealed mutations in stress response (KEGS1_01) and biofilm-related genes (KEGS1_40), but no mutations were found in the pigment biosynthetic (*pig*) gene clusters. In conclusion, this study suggests the potential of microbial pigments for future biotechnological applications, including use as functional fabric dyes and SPF enhancers. However, further research is recommended to fully understand their properties.

Key words:

Microbial pigments, antibacterial, antioxidant, photoprotection, fabric dye