EXPLORING SUSTAINABLE DYE SOLUTIONS: THE ROLE OF FUNGI-DERIVED DYES IN TEXTILE INDUSTRY

Nathalia A. Lupetti[1], Marcelo O. Heiderich[1], Maiara H. Simone[1], Leticia S. Kruze[1], Gabriel A. Tochetto[1]*, Amanda Dalalibera[1], André A. Battistelli[1], Ana Paula S. Immich[2] & Maria E. Nagel-Hassemer[1]

[1] Water Reuse Laboratory, Department of Sanitary and Environmental Engineering, Federal University of Santa Catarina, Florianópolis, Brazil.
[2] Department of Chemical Engineering and Food Engineering, Federal University of Santa Catarina, Florianópolis, Brazil
** Corresponding author's email address: gabriel.tochetto@posgrad.ufsc.br*

ABSTRACT

This review examines the historical and current use of dyes, emphasizing the environmental impact of synthetic dyes and the potential of natural dyes, particularly those derived from fungi, as sustainable alternatives to the textile industry. While synthetic dyes are widely used for their desirable properties, they pose environmental risks, necessitating the exploration of eco-friendly options. Fungal dyes are promising due to their stability and diverse color production, though challenges such as low water solubility and poor light resistance remain. The review highlights various studies on microbial dye production, their application in textile dyeing, and the need for continued research into sustainable dyeing techniques.

Keywords: Colorant. Natural pigment. Microorganism. Textile industry.

1 INTRODUCTION

The use of dyes dates back centuries, with ancient civilizations utilizing plant extracts, minerals, and even insects to color textiles, food, and other objects[1]. Initially, dyes were sourced from natural materials, but the Industrial Revolution and advances in chemistry ushered in the era of synthetic dyes, which now dominate the market[2]. Today, dyes are employed in various products, including food, beverages, cosmetics, textiles, and pharmaceuticals, and can be categorized into synthetic and natural dyes. Dyes play a crucial role in the appearance and appeal of products, significantly influencing consumer purchasing decisions.

However, large-scale dye production has led to numerous environmental issues, such as water pollution, aquatic toxicity, and soil accumulation, necessitating the development of more environmentally friendly alternatives. In response, research has focused on using fungi, bacteria, and algae as common sources of microbial dyes as natural and sustainable dye alternatives[3].

Fungi, in particular, are of significant interest due to their widespread availability and the favorable properties of their derived dyes, such as color stability and resistance, making them suitable for dyeing fabrics like wool and silk[4]. Fungi produce colored metabolites, including quinones, flavonoids, rubramines, and carotenoids, which exhibit substantial structural and chemical diversity, resulting in various colors. These compounds present a promising, eco-friendly alternative to conventional dyes[3].

This review aims to provide a comprehensive analysis of the production and application of microbial dyes, particularly those derived from fungi, and their potential as sustainable dye solutions.

2 MATERIAL & METHODS

The present literature study consisted of a bibliographic review on the use of microorganisms to obtain natural dyes for application in textile dyeing. The following Boolean operators were used: "dye" OR "natural pigments" AND "fungi" OR "microorganism" AND "textile" OR "dyeing" in the Web of Science and Scopus databases. Only scientific articles that involved the dyeing of fabrics were considered.

3 RESULTS & DISCUSSION

In nature, some microorganisms, such as fungi, produce colored metabolites that are used as a form of resistance and protection against ultraviolet radiation and other fungi and/or bacteria[5]. These compounds have a wide structural and chemical diversity, providing a large variety of colors[2]. Numerous studies in the literature report the production of dyes and pigments derived from microorganisms, such as quinones, flavonoids, rubramines, and carotenoids[6,7].

One of the main ways to obtain microbial-based dyes is from fungi, bacteria, and algae, with fungal dyes being of great interest. The possibilities for isolating fungi are vast, as they can be found virtually anywhere; however, there is a trend to obtain these microorganisms from soil and wood (usually decayed), as demonstrated in Table 1.

Velmurugan et al.[8] conducted an extensive study aiming to isolate fungi capable of producing colored metabolites from 51 soil samples, while Hernández et al.[1] produced two dyes from the metabolites of fungi *Penicillium murcianum* and *Talaromyces australis* isolated from decayed wood (*Nothofagus* ssp.). Weber et al.[4] and Hinsch et al.[9] also isolated fungi from wood samples.

Table 1 Key Fungi Used in Dye Extraction for Textile Dyeing.

Fungus	Origin	Color	Fabric	Ref.
Chlorociboria aerugionosa	Wood	Green	Cotton, wool, polyamide, polyester, polyacrylic	4,9
Emericella nidulans	Soil	Reddish-brown	Cotton	8
Fusariun verticillioides	Soil	Red	Cotton	8
Isaria farinose	Soil	Pink	Cotton	8
Monascus purpureus	Soil	Red	Cotton	8
Monascus JCM 22619	Commercial	Red	Silk	10
Penicillium murcianum	Wood	Yellow	Wool	1,11
Penicillium purpurogenum	Soil	Yellow	Cotton	8
Scytalidium cuboideum	Wood	Red	Cotton, wool, polyamide	4,9
Scytalidium ganodermophtherum	Wood	Yellow	Cotton, wool, polyamide, polyester, polyacrylic	4,9
Serratia marcescens jx1	Soil	Red	Acrylic, cotton, polylatic acid, polyamide	7
Talaromyces australis	Wood	Red	Wool	1,11

The dyes used by Hernández et al.[1] were employed individually and in mixtures (between yellow and red) for wool dyeing. Good colorfastness to washing was observed, maintaining a $\Delta E \leq 2$ in most tests. The color fixation to the fabric was also evaluated through wet and dry rubbing, presenting values below 4 under all conditions, indicating good interaction between the dye and the fabric. In addition to these conditions, the fabric dyed with fungal dyes did not show significant alterations or loss of tensile strength. The authors state that the pigments produced by extracellular metabolism can be considered dyes, as they have water solubility and fabric affinity. The dyeing conditions used, according to the authors, are consistent with those employed in industrial processes[1,11].

Weber et al.[4] concluded that dyeing with fungal dyes presents greater color intensity when the drip (layering) method is used compared to the immersion (saturation) process. The drip dyeing process is recognized for requiring less water and energy, although traditional baths show good color fixation and fastness. This result was not found in this work, where ΔE was above 11.

Hinsch et al.[9] continued Weber et al.[4] study, investigating some parameters in greater depth, concluding that the three dyes obtained by the fungal route are stable over time. The green (xylindein) and red (draconin) exhibited wash resistance, and the green had good perspiration resistance. Generally, the three dyes have a higher dye affinity for polyester, moderate interaction with wool, polyacrylic, and polyamide, while the efficacy for dyeing cotton was not adequate.

The modification of the *Serratia marcescens* jx1 strain produced a red dye known as prodigiosin. It was found that this metabolite dyed acrylic, polyamide, and polylactic acid with higher saturation compared to cotton. This behavior can be explained by an electrostatic interaction, as the medium is acidic and prodigiosin has a cationic charge. Cotton was unable to establish strong bonds with the dye's functional group, resulting in lower color saturation[7].

The fungus *Monascus* is well known for producing red-colored metabolites, so Yang et al.[10] evaluated the dyeing properties on silk fabrics. The study revealed that the dye had good friction resistance (>4), indicating good fixation and absorption (up to 89%) of the color on the fabric. However, the dye is sensitive to heat and light and has low solubility, justifying the low lightfastness (level 3).

Genetic modification of microorganisms is a growing field, enabling the creation of organisms with desirable specificities. The study by Liu et al.[7] reported an increase in purity (98%) and yield (109%) of red pigments by mutating the Serratia marcescens jx1 strain using microwaves.

Despite being a natural dye obtained from microorganisms, some authors emphasize the need for additional tests on antimicrobial properties[1] and possible adverse skin reactions in consumers[4,8].

4 CONCLUSION

In the technical domain, chemically synthesized dyes exhibit desirable properties, justifying their extensive use on an industrial scale. However, their dependence on finite resources and environmental toxicity raises concerns about their sustainability. Natural dyes emerge as an alternative for cleaner production, offering a range of shades with different saturations. Although fungal dyes provide good stability and biotechnological availability for high yields, they generally exhibit low water solubility and color fixation, and have poor resistance when exposed to light. Therefore, future research into advancing new, more sustainable, and economically viable textile dyeing techniques is essential for the continuity of the textile industry.

REFERENCES

[1] HERNÁNDEZ, V. A., GALLEGUILLOS, F., THIBAUT, R., MULLER, A. 2019. J. Text. I. 110. 61-66.
[2] INDUMATHY, K., KANNAN, K. P. 2020. J. Text. I. 111. 148-154
[3] ORONA-NAVAR, A., AGUILAR-HERNÁNDEZ, I., NIGAM, K. D. P., CERDÁN-PASARÁN, A., ORNELAS-SOTO, N. 2021. J. Biotech. 332. 29-53.
[4] WEBER, G., CHEN, H., HINSCH, E., FREITAS, S., ROBINSON, S. 2014. Color Technol. 130. 445-452.
[5] EISENMAN, H., CASADEVALL, A. 2012. Appl. Microbiol. Biotechnol. 93. 931-940
[6] ALIHOSSEINI, F., JU, K., LANGO, J., HAMMOCK, B. D., SUN, G. 2008. Biotechnol. Prog. 24. 742-747.
[7] LIU, X., WANG, Y., SUN, S., ZHU, C., XU, W., PARK, Y., ZHOU, H. 2013. 43. 271-284.
[8] VELMURUGAN, P., KIM, M., PARK, J., KARTHIKEYAN, K., LAKSHMANAPERUMALSAMY, P., LEE, K., PARK, Y., OH, B. 2010. Fiber Polym. 11. 598-605.
[9] HINSCH, E. M., WEBER, G., CHEN, H., ROBINSON, S. C. 2015. J. Text. Appar. Technol. Manag. 9. 1-11.
[10] YANG, M., YU, Y., ZHAI, H., SHENG, J., XING, T., CHEN, G. 2018. J. Text. I. 109. 1329-1334.
[11] HERNÁNDEZ, V. A., GALLEGUILLOS, F. A., SAGREDO, N., MACHUCA, A. 2018. Coat. 8(2). 77.

ACKNOWLEDGEMENTS

Thank Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for granting a scholarship and to the Water Reuse Laboratory (LaRA) for the technical support.