International Journal of Current Science Research
www.drbgrpublications.in

Phytogenic Cadmium Nanoparticles with Tunable Optical Behavior for Environmental Applications

C.Ramalakshmi[1], S.Thanga parameshwari[2], R.Mariselvam[3], V.P.Saranya[4], A.Sabaridasan[5*]

[1]*Department of Food and Nutrition, St.Eugene University, Zambia.*

[2]*Tamil Institute of Science and Technology, Seeniyapuram, Tenkasi, Tamil Nadu, India.*

[3]*Saraswathi Institute of Lifescience, Therkkumadatthur, Tenkasi, Tamil Nadu, India.*

[4]*Department of Biotechnology, Manonmanium Sundaranar University, Tirunelveli, Tamil Nadu, India.*

[5]*PG & Research Department of Biotechnology, Sri Vinayaga College of Arts & Science, Ulundurpet, Kallakurichi (Dt), Tamil Nadu, India*

**Corresponding author Email: sabari.biotech@gmail.com*

Abstract

This study explores the synthesis of cadmium nanoparticles using Emblica officinalis extract and evaluates their optical properties through UV–Visible spectroscopy. A prominent absorption peak observed at 352.88 nm, attributed to surface plasmon resonance (SPR), confirms the successful formation of cadmium nanoparticles within the nanoscale range. An additional shoulder at 431.21 nm likely arises from phytochemical interactions and surface defects. The optical data suggest the particles fall within the 10–50 nm size range, aligning with predictions from Mie theory. The plant extract functions effectively as both a reducing and stabilizing agent, facilitating the green synthesis of nanoparticles with strong optical activity suitable for environmental and catalytic applications. Furthermore, the absorption characteristics of Eosin dye were examined to assess its degradation under visible light in the presence of a photocatalyst. Initially, the dye exhibited a strong absorption band between 400–600 nm, peaking around 515–520 nm due to π→π transitions. Over time, a consistent decline in absorbance was observed, indicating the progressive degradation of the dye's chromophoric system. By 48 hours, the visible absorption had nearly vanished, suggesting substantial dye breakdown without the formation of detectable intermediates. These findings demonstrate the potential of the synthesized nanoparticles in photocatalytic dye degradation, supporting their use in sustainable wastewater treatment technologies.*

Keywords: Emblica officinalis; cadmium nanoparticles; Eosin; photocatalytic dye degradation.

Citation: C.Ramalakshmi, S.Thanga parameshwari, R.Mariselvam, V.P.Saranya, A.Sabaridasan. "Phytogenic Cadmium Nanoparticles with Tunable Optical Behavior for Environmental Applications" International Journal of Current Science Research (IJCSR) e-ISSN: 2454-5422: 11.5 (2025): 70-82

Introduction

Synthetic dyes are man-made chemical substances widely used to impart color to various materials. Unlike natural dyes derived from plants, animals, or minerals, synthetic dyes are created through organic chemical reactions, often utilizing petroleum-based compounds (Ardila-Leal *et al.*, 2021). The development of synthetic dyes began in the mid-19th century, notably with the discovery of mauveine by William Henry Perkin in 1856. Since then, the industry has witnessed rapid growth, leading to the production of thousands of synthetic dyes in a wide range of shades and chemical compositions (Holme, 2006). These dyes are classified into several types, such as acid dyes, basic dyes, direct dyes, reactive dyes, and disperse dyes, based on their chemical structure and method of application. Their ability to produce vibrant, long-lasting colors, combined with the relative ease and cost-effectiveness of manufacturing, has made synthetic dyes an integral part of modern industries (IARC, 2010).

The uses of synthetic dyes are vast and span numerous sectors. In the textile industry, synthetic dyes are the principal coloring agents for fabrics like cotton, wool, silk, polyester, and nylon (Berradi *et al.,* 2019). They are valued for their wide color range, consistency, and fastness properties, meaning they resist fading from light exposure, washing, and perspiration. Beyond textiles, synthetic dyes are crucial in the paper industry for coloring paper products, including writing papers, packaging materials, and decorative papers (Alegbe & Uthman, 2024). The food industry utilizes synthetic dyes to enhance the visual appeal of products; common food dyes like Tartrazine (yellow) and Allura Red are synthesized through chemical processes. Pharmaceuticals and cosmetics also rely heavily on synthetic dyes. In medicines, dyes are used for coating tablets to improve their appearance and facilitate identification, while in cosmetics, dyes are essential for lipsticks, eyeliners, nail polishes, and hair dyes (Dey & Nagababu, 2022). Moreover, synthetic dyes are employed in biological and clinical research for staining cells and tissues to enhance microscopic visualization, as well as in the manufacture of inks, paints, plastics, and leather goods (Adeyemo *et al.*, 2018).

The applications of synthetic dyes are specialized according to the dye type and the substrate to which it is applied. For example, acid dyes are typically used for dyeing protein fibers such as wool, silk, and nylon under acidic conditions (Pizzicato *et al.*, 2023). Basic dyes, which are cationic, are suitable for materials like acrylic fibers and are known for their brilliant hues. Reactive dyes form covalent bonds with cellulosic fibers like cotton, providing excellent wash-fastness. Direct dyes, on the other hand, are applied to cellulosic fibers without the need for a binding agent, although their fastness properties are generally lower than reactive dyes (Salleh *et al.,* 2011). Disperse dyes are mainly used for dyeing synthetic fibers such as polyester and acetate. Specialized applications also include fluorescent dyes for high-visibility clothing, dyes for inkjet printing, and dyes used in electronic and optical devices. In microbiology and pathology, synthetic dyes like methylene blue, safranin, and eosin are used extensively for staining techniques that help distinguish between different types of cells and tissues under a microscope (Al-Etaibi & El-Apasery, 2023).

Despite their many advantages, synthetic dyes pose significant environmental challenges. The dye manufacturing and application processes generate a large volume of waste, including dye effluents that are often discharged into natural water bodies without adequate treatment (Das *et al.,* 2023). These effluents contain a mixture of dyes, salts, surfactants, heavy metals, and organic chemicals, contributing to water pollution. Synthetic dyes are typically designed to resist degradation by light, water, and microbial activity, which, while beneficial for product durability, renders them highly persistent in the environment (Jamee & Siddique, 2019). The presence of dyes in water bodies reduces light penetration, affecting photosynthesis in aquatic plants and disrupting ecosystems. Additionally, some synthetic dyes and their degradation products are toxic, mutagenic, or carcinogenic to aquatic life and humans (Berradi *et al.*, 2019). Azo dyes, in particular, can break down under anaerobic conditions to produce aromatic amines, many of which are known carcinogens. Furthermore, the production of synthetic dyes often involves hazardous chemicals and generates significant air emissions and solid waste, further exacerbating environmental degradation (Zafar *et al.*, 2022).

Eosin dye, a synthetic dye belonging to the xanthene class, deserves particular attention due to its widespread application and environmental concerns. Eosin is commonly used in biological staining, especially in hematoxylin and eosin (H&E) staining protocols in histology and pathology (Sarode *et al.,* 2022). It imparts a bright pink to red coloration to cytoplasmic components and connective tissues, allowing for clear differentiation between cell structures under a microscope. Eosin exists in two main forms: eosin Y (yellowish) and eosin B (bluish). Apart from biological applications, eosin dyes are also used in inks, cosmetics, textile dyeing, and as pigments in various products (Gamble & Wilson, 2008). In cosmetics, for instance, eosin derivatives are used to achieve specific shades in products like blushes and lipsticks. Eosin's fluorescent properties have also made it useful in research fields requiring fluorescence microscopy.

However, the environmental impact of eosin dye raises significant concerns. Like many synthetic dyes, eosin is not readily biodegradable, leading to its persistence in aquatic environments (Mansour *et al.*, 2023). Effluents containing eosin can impart color to water bodies, affecting aesthetic quality and ecological health. Even at low concentrations, the presence of eosin in water can disrupt the photosynthetic activity of aquatic plants by blocking sunlight, thereby affecting the entire aquatic food web (Rápó & Tonk, 2021). Additionally, eosin and its degradation products may exert toxic effects on aquatic organisms, including fish, amphibians, and invertebrates. Studies have indicated that eosin exposure can lead to oxidative stress, DNA damage, and physiological disturbances in aquatic animals (Lushchak *et al.*, 2018). In humans, eosin is generally considered safe in controlled laboratory use, but improper disposal and environmental accumulation pose potential health risks through contaminated water supplies (Gerba, 2015).

Moreover, the manufacture of eosin dye involves the use of hazardous substances like bromine and phthalic anhydride, which themselves carry environmental and occupational health risks. Bromine, for instance, is highly toxic and poses dangers to workers in manufacturing plants if proper handling procedures are not enforced. The production process generates chemical waste that requires careful management to prevent air, water, and soil contamination. In many parts of the world, especially in developing countries where regulatory oversight is limited, dye effluents are released into the environment without adequate treatment, compounding the ecological threat (Saxena, 2024). Conventional wastewater treatment methods are often insufficient to remove synthetic dyes like eosin due to their chemical stability. As a result, advanced treatment technologies such as adsorption, advanced oxidation processes (AOPs), membrane filtration, and bioremediation are being researched and implemented to mitigate dye pollution (Tripathi *et al.*, 2023).

In response to the environmental issues associated with eosin and other synthetic dyes, significant efforts are being made to develop more sustainable alternatives. Research into biodegradable dyes derived from natural sources is gaining momentum. Additionally, green chemistry approaches aim to redesign synthetic dye production processes to minimize hazardous by-products and energy consumption (Pradeepthi *et al.*, 2023). For eosin, researchers are investigating photocatalytic degradation methods, wherein light-driven catalysts break down dye molecules into less harmful substances. Biodegradation using dye-degrading microorganisms is another promising area, though challenges related to efficiency and scalability remain. Policymakers are also stepping up by enforcing stricter regulations on industrial effluent discharge and encouraging the adoption of cleaner production technologies (Zhao *et al.*, 2005).

Synthetic dyes have revolutionized many industries through their versatility, vibrant colors, and application-specific properties. However, their environmental footprint is a significant concern, as dye pollutants contribute to water contamination, ecosystem disruption, and potential health risks (Manzoor & Sharma, 2020). Eosin dye, while invaluable in medical and research fields, exemplifies these challenges due to its persistence and toxicity in aquatic environments (Dutta *et al.*, 2024). Addressing these issues requires a multifaceted approach involving technological innovation, stricter environmental regulations, industry responsibility, and a shift toward sustainable materials. Only through such comprehensive efforts can we continue to benefit from the remarkable properties of synthetic dyes while safeguarding environmental and public health (Matavos-Aramyan, 2024).

The present study deals with the cadmium nanoparticles synthesized using *Emblica officinalis* extract and analyze the degradation ability of eocin dyes.

Procedure

Plant collection and extraction: Fresh *Emblica officinalis* leaves were gathered from a cultivated region in the Coutrallam hills. After collection, the leaves were air-dried in the shade and subsequently pulverized into a fine powder using a mechanical grinder. To prepare the plant extract, 10 grams of the powdered material were combined with 100 mL of distilled water and heated between 60°C and 80°C for about 20 minutes. The resulting solution was allowed to cool to ambient temperature and then filtered through Whatman No.1 filter paper to obtain a clear aqueous extract.

Synthesis of cadmium nanoparticles: To synthesize cadmium nanoparticles, 50 mL of the prepared *Emblica officinalis* leaf extract was gradually added to 50 mL of an aqueous cadmium nitrate [$Cd(NO_3)_2$] solution (1 mM) under constant stirring at room temperature. The reaction mixture was continuously stirred for 3–4 hours, during which a visible color change was observed, indicating nanoparticle formation. The solution was then incubated for 24 hours to ensure complete reduction and stabilization. The resulting colloidal suspension was centrifuged at 10,000 rpm for 15 minutes to separate the nanoparticles. The pellet was washed several times with distilled water and ethanol to remove any unreacted components or impurities. Finally, the purified cadmium nanoparticles were dried at 60°C and stored in airtight containers for further analysis.

Characterization of EOCD nanoparticles: The synthesized cadmium (Cd) nanoparticles were characterized using UV–Visible spectroscopy to assess their optical properties and estimate particle size. A stable colloidal suspension was prepared by dispersing a small amount of the dried Cd nanoparticles in distilled water, followed by ultrasonication to achieve uniform dispersion. The absorbance spectrum of the suspension was recorded over the wavelength range of 200–1000 nm using a UV–Vis spectrophotometer, with distilled water as the reference and a 1 cm quartz cuvette for measurement.

Photochatalytic activity of EOCD nanoparticles against eosin dye under solar light: To assess the photocatalytic performance of the synthesized cadmium nanoparticles, an aqueous solution of Eosin dye (10 mg/L) was prepared. A fixed quantity of Cd nanoparticles (typically 10 mg) was dispersed in 100 mL of the dye solution using ultrasonication for uniform mixing. Prior to light exposure, the suspension was magnetically stirred in the dark for 30 minutes to establish adsorption–desorption equilibrium between the dye molecules and the nanoparticle surfaces.

The photocatalytic degradation experiment was then conducted under natural sunlight between 10:00 AM and 2:00 PM on clear, sunny days to ensure consistent light intensity. During irradiation, aliquots of 5 mL were withdrawn at regular time intervals (e.g., every 6 hours), centrifuged to remove the catalyst particles, and the supernatant was analyzed using a UV–Visible spectrophotometer. The absorbance was recorded in the range of 400–600 nm, with the maximum absorbance peak at ~515–520 nm monitored to evaluate dye degradation.

Result and Discussion

The UV–Visible absorption spectrum of cadmium nanoparticles synthesized using *Emblica officinalis* extract exhibits characteristic peaks indicative of successful nanoparticle formation and distinct optical properties (Figure 1). The spectrum shows a strong absorbance in the UV region, with a prominent peak centered around 352.88 nm, followed by a less intense shoulder at 431.21 nm. The strong absorption at 352.88 nm can be attributed to surface plasmon resonance (SPR), a phenomenon typically observed in metal and semiconductor nanoparticles, indicating the presence of cadmium in nanoscale form. This absorption feature reflects electronic transitions associated with the cadmium core and the surrounding phytochemical stabilizers from the plant extract.

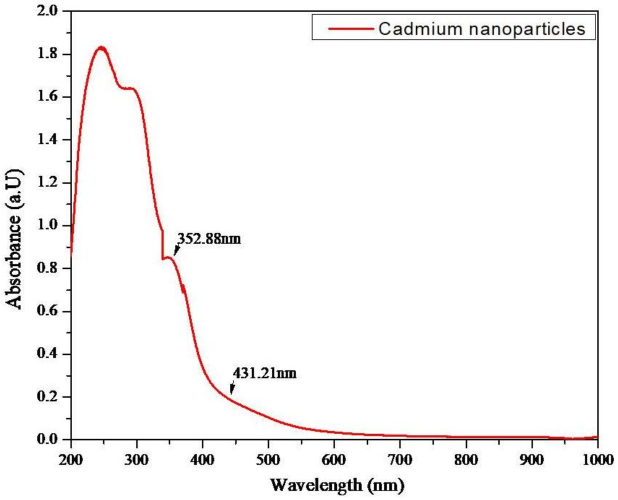

Figure 1: UV/Vis spectral data of cadmium nanoparticles.

The shoulder at 431.21 nm suggests potential interband transitions or surface states arising from phytochemical interactions and particle surface irregularities. The gradual decline in absorbance beyond this point, with minimal absorption in the visible and near-infrared regions, is consistent with the optical behavior of small-sized cadmium nanoparticles.

To estimate the particle size from the absorption spectrum, Mie theory provides a suitable approach. This theory describes the interaction of light with spherical particles and correlates scattering and absorption efficiencies with particle size, refractive index, and wavelength. The broad and intense SPR peak around 352.88 nm implies that the synthesized cadmium nanoparticles are within the quantum confinement region, typically ranging from 10 to 50 nm. By comparing the experimental absorption profile with theoretical Mie scattering curves, the particle size is inferred to be in the optimal nanoscale range for strong optical activity. The UV–Vis analysis confirms that *Emblica officinalis* serves as an effective reducing and stabilizing agent, producing cadmium nanoparticles with significant optical response and appropriate size distribution suitable for applications in sensing, catalysis, and environmental remediation.

The UV–Visible absorption spectrum of Eosin dye reveals significant optical features characteristic of its molecular structure and conjugated chromophores. A strong and broad absorption band is observed in the visible region, ranging from approximately 400 to 600 nm, with a maximum absorbance around 515–520 nm. This prominent peak corresponds to $\pi \rightarrow \pi^*$ electronic transitions within the aromatic and xanthene moieties of the Eosin dye, which are responsible for its bright red-pink coloration.

The intense absorbance in the visible region highlights the dye's efficiency in light harvesting, which is critical for applications such as dye-sensitized solar cells, biological staining, and photocatalytic degradation studies. The steep rise in absorbance from 300 nm and the broad plateau indicate a well-established conjugated system and a high degree of electronic delocalization. Minor fluctuations or shoulders observed around 450–480 nm may be due to additional transitions or vibrational sublevels within the excited states.

Beyond 600 nm, the absorbance drops sharply and approaches zero, indicating negligible absorption in the red and near-infrared regions. This spectral behavior is typical of Eosin Y-type dyes and confirms the absence of extended conjugation beyond the xanthene core (Figure 2). The clear baseline and absence of secondary peaks in the near-infrared region suggest a stable molecular structure without significant degradation or impurities.the UV–Vis spectrum of Eosin dye confirms its strong absorption in the visible region and supports its application in photocatalytic studies, particularly for monitoring degradation processes where visible-light responsiveness is essential.

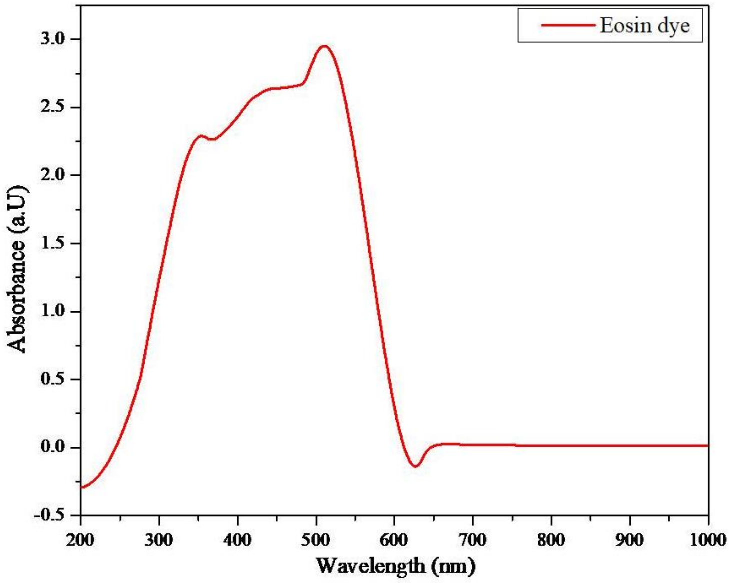

Figure 2: Eosin dye UV/Vis spectra.

The time-dependent UV–Visible absorption spectra of Eosin dye in the presence of a photocatalyst demonstrate a clear trend of progressive degradation under visible light exposure. Initially, at 0 minutes, the dye solution exhibits a strong and well-defined absorption peak centered around 515–520 nm, which corresponds to π→π* electronic transitions in the conjugated xanthene framework of Eosin. This high-intensity peak reflects the pristine dye concentration and its strong coloration (Figure 3).

As the photocatalytic reaction proceeds, a gradual decrease in absorbance intensity is observed across successive time intervals—5, 10, 15, 30, 45, 60, 120 minutes, and up to 24 and 48 hours. This steady decline in peak height indicates the breakdown of the dye's chromophoric structure, likely due to cleavage of the xanthene ring and decolorization via oxidative degradation pathways. The reduction in absorption is particularly pronounced in the visible region, confirming the disruption of the dye's extended conjugated system.

Importantly, no new absorption bands are detected throughout the monitoring period, suggesting that intermediate degradation products are either transient or non-absorbing within the UV–Vis range, implying a route toward complete mineralization. Additionally, the UV region (around 250–350 nm) also shows a decrease in intensity, indicating the concurrent decomposition of side chains and aromatic groups.

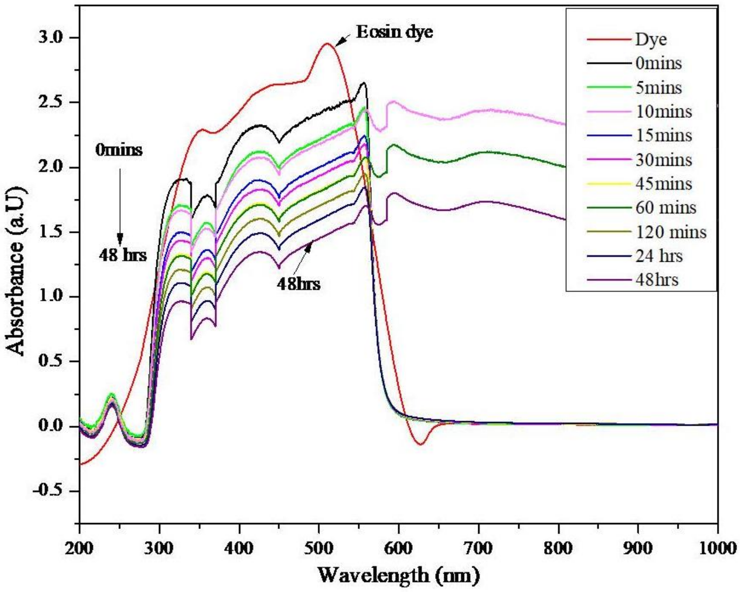

Figure 3: Solar degradation of eosin dye by cadmium nanoparticles.

By the 48-hour mark, the spectrum shows minimal absorbance across the visible region, signifying near-complete degradation of Eosin dye. These findings highlight the effectiveness of the applied photocatalyst in facilitating the breakdown of stable organic dyes and support its application in environmental cleanup strategies such as wastewater treatment.

Conclusion

The UV–Visible spectral analysis confirms the successful synthesis of cadmium nanoparticles using *Emblica officinalis* extract as a green reducing and stabilizing agent. The strong absorbance peak at 352.88 nm, characteristic of surface plasmon resonance, indicates the formation of cadmium nanoparticles with nanoscale dimensions. The presence of a secondary shoulder at 431.21 nm points to surface-related optical transitions, likely influenced by phytochemicals from the plant extract. Estimation of particle size using Mie theory suggests the nanoparticles fall within the optimal size range of 10–50 nm, suitable for applications requiring strong optical responsiveness.

In parallel, the absorption spectrum of Eosin dye exhibits a dominant peak around 515–520 nm, corresponding to its $\pi \rightarrow \pi^*$ electronic transitions and highlighting its suitability for light-driven processes. The photocatalytic degradation study reveals a systematic decrease in absorbance intensity over time, indicating efficient breakdown of the dye under visible light. The absence of new spectral peaks and the decline in both visible and UV absorbance regions suggest near-complete degradation and minimal formation of persistent intermediates.

Overall, these findings underscore the potential of *Emblica officinalis*-derived cadmium nanoparticles as effective photocatalysts for environmental applications, particularly in the degradation of synthetic dyes like Eosin. The study supports the integration of green-synthesized nanomaterials in sustainable wastewater treatment technologies.

Reference

Ardila-Leal, L. D., Poutou-Piñales, R. A., Pedroza-Rodríguez, A. M., & Quevedo-Hidalgo, B. E. (2021). A Brief History of Colour, the Environmental Impact of Synthetic Dyes and Removal by Using Laccases. *Molecules (Basel, Switzerland)*, 26(13), 3813.

Holme, I. (2006). Sir William Henry Perkin: a review of his life, work and legacy. *Coloration Technology*, 122(5), 235-251.

IARC Working Group on the Evaluation of Carcinogenic Risks to Humans. Some Aromatic Amines, Organic Dyes, and Related Exposures. Lyon (FR): International Agency for Research on Cancer; 2010. (IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, No. 99.) General Introduction to the Chemistry of Dyes.

Berradi, M., Hsissou, R., Khudhair, M., Assouag, M., Cherkaoui, O., El Bachiri, A., & El Harfi, A. (2019). Textile finishing dyes and their impact on aquatic environs. *Heliyon*, 5(11), e02711.

Alegbe, E. O., & Uthman, T. O. (2024). A review of history, properties, classification, applications and challenges of natural and synthetic dyes. *Heliyon*.

Dey, S., & Nagababu, B. H. (2022). Applications of food color and bio-preservatives in the food and its effect on the human health. *Food Chemistry Advances*, 1, 100019.

Adeyemo, S., Akinloye, A., & Adekanmi, G. (2018). The use of plant dyes for microbial staining and identification: An eco-friendly and non-toxic alternative method. *J. Adv. Biol. Biotechnol*, 16, 1-10.

Pizzicato, B., Pacifico, S., Cayuela, D., Mijas, G., & Riba-Moliner, M. (2023). Advancements in Sustainable Natural Dyes for Textile Applications: A Review. *Molecules (Basel, Switzerland)*, 28(16), 5954.

Salleh, M. A. M., Mahmoud, D. K., Karim, W. A. W. A., & Idris, A. (2011). Cationic and anionic dye adsorption by agricultural solid wastes: a comprehensive review. *Desalination*, 280(1-3), 1-13.

Al-Etaibi, A. M., & El-Apasery, M. A. (2023). Can Novel Synthetic Disperse Dyes for Polyester Fabric Dyeing Provide Added Value?. *Polymers*, 15(8), 1845.

Das, S., Cherwoo, L., & Singh, R. (2023). Decoding dye degradation: Microbial remediation of textile industry effluents. *Biotechnology notes (Amsterdam, Netherlands)*, 4, 64–76.

Jamee, R., & Siddique, R. (2019). Biodegradation of Synthetic Dyes of Textile Effluent by Microorganisms: An Environmentally and Economically Sustainable Approach. *European Journal of Microbiology & Immunology*, 9(4), 114–118.

Berradi, M., Hsissou, R., Khudhair, M., Assouag, M., Cherkaoui, O., El Bachiri, A., & El Harfi, A. (2019). Textile finishing dyes and their impact on aquatic environs. *Heliyon*, 5(11), e02711.

Zafar, S., Bukhari, D. A., & Rehman, A. (2022). Azo dyes degradation by microorganisms - An efficient and sustainable approach. *Saudi Journal of Biological Sciences*, 29(12), 103437.

Sarode, S. A., Pradeep, G. L., Prakash, N., Mahajan, A., & Mangle, N. (2022). Exploring a safer alternative to eosin in soft tissue staining. *Journal of Oral and Maxillofacial Pathology: JOMFP*, 26(4), 603.

Gamble, M., & Wilson, I. (2008). The hematoxylins and eosin. Theory and practice of histological techniques, 6, 121-34.

Mansour, M. S., Farid, Y., Nosier, S. A., Adli, O., & Abdel-Aziz, M. H. (2023). Removal of Eosin Yellow dye from industrial wastewater using UV/H2O2 and photoelectro-Fenton techniques. *Journal of Photochemistry and Photobiology A: Chemistry*, 436, 114411.

Rápó, E., & Tonk, S. (2021). Factors Affecting Synthetic Dye Adsorption; Desorption Studies: A Review of Results from the Last Five Years (2017-2021). *Molecules (Basel, Switzerland)*, 26(17), 5419.

Lushchak, V. I., Matviishyn, T. M., Husak, V. V., Storey, J. M., & Storey, K. B. (2018). Pesticide toxicity: a mechanistic approach. *EXCLI Journal*, 17, 1101–1136.

Gerba C. P. (2015). Environmentally Transmitted Pathogens. *Environmental Microbiology*, 509–550.

Saxena, S. (2024). Pyrolysis and beyond: Sustainable valorization of plastic waste. Applications in Energy and Combustion Science, 100311.

Tripathi, M., Singh, S., Pathak, S., Kasaudhan, J., Mishra, A., Bala, S., Garg, D., Singh, R., Singh, P., Singh, P. K., Shukla, A. K., & Pathak, N. (2023). Recent Strategies for the Remediation of Textile Dyes from Wastewater: A Systematic Review. *Toxics*, 11(11), 940.

Pradeepthi, K., Rajani, K., Rao, G., Sravya, T., Wahed, S. A., & Sailaja, J. (2023). Evaluation of biosafe alternative to eosin in hematoxylin and eosin staining procedure: A comparative study. *Journal of Oral and Maxillofacial Pathology: JOMFP*, *27*(2), 424.

Zhao, J., Chen, C., & Ma, W. (2005). Photocatalytic degradation of organic pollutants under visible light irradiation. *Topics in catalysis*, 35, 269-278.

Manzoor, J., & Sharma, M. (2020). Impact of textile dyes on human health and environment. In Impact of textile dyes on public health and the environment (pp. 162-169). IGI Global Scientific Publishing.

Dutta, S., Adhikary, S., Bhattacharya, S., Roy, D., Chatterjee, S., Chakraborty, A., Banerjee, D., Ganguly, A., Nanda, S., & Rajak, P. (2024). Contamination of textile dyes in aquatic environment: Adverse impacts on aquatic ecosystem and human health, and its management using bioremediation. *Journal of Environmental Management*, 353, 120103.

Matavos-Aramyan, S. (2024). Addressing the microplastic crisis: A multifaceted approach to removal and regulation. *Environmental Advances*, 100579.