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Review

# Detoxification of azo dyes in the context of environmental processes

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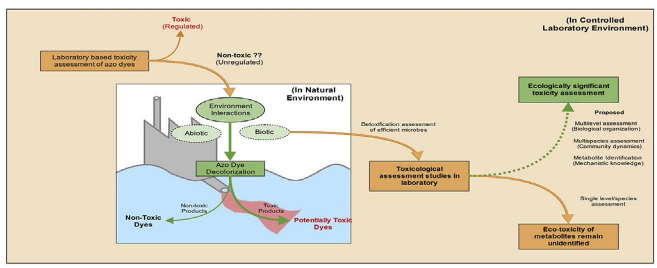
## HIGHLIGHTS

- Dye classification neglects environmental toxicity of the presumably non-toxic dyes.
- Environmental processes determine the fate and consequences of azo dyes.
- Current studies on microbial dye detoxification lack ecological relevance.
- Research framework for environmentally relevant dye detoxification is proposed.
- Suggests role of dye-microbe-environment interactions for environmental protection.

## GRAPHICAL ABSTRACT

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## ABSTRACT

Azo dyes account for >70% of the global industrial demand (~9 million tons). Owing to their genotoxic/carcinogenic potential, the annual disposal of ~4,500,000 tons of dyes and/or degraded products is an environmental and socio-economic concern. In comparison to physico-chemical methods, microbe-mediated dye degradation is considered to be low-input, cost-effective and environmentally-safe. However, under different environmental conditions, interactions of chemically diverse dyes with metabolically diverse microbes produce metabolites of varying toxicity. In addition, majority of studies on microbial dye-degradation focus on decolorization with least attention towards detoxification. Therefore, the environmental significance of microbial dye detoxification research of past >3 decades is critically evaluated with reference to dye structure and the possible influence of microbial interactions in different environments. In the absence of ecosystem-based studies, the results of laboratory-based studies on dye degradation, metabolite production and their genotoxic impact on model organisms are used to predict the possible fate and consequences of azo dyes/metabolites in the environment. In such studies, the predominance of fewer numbers of toxicological assays that too at lower levels of biological organization (molecular/cellular/organismic) suggests its limited ecological significance. Based on critical evaluation of these studies the recommendations on inclusion of multilevel approach (assessment at multiple levels of biological organization), multispecies microcosm approach and native species approach in conjunction with identification of dye metabolites have been made for future studies. Such studies will bridge the gap between the fundamental knowledge on dye-microbe-environment interactions and its application to combat dye-induced environmental toxicity.

Thus an environmental perspective on dye toxicity in the background of dye structure and effects of environmental processes has been developed. Based on past 3 decades of research on microbial dye detoxification, the current state of knowledge has been analyzed, environmental relevance of these

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studies was ascertained, research gaps in microbe-mediated azo dye detoxification have been identified and a research framework emphasizing a better understanding of complex interactions between dye-microbe and environmental processes has been proposed. It provides directions for undertaking environmentally sound microbial dye detoxification research.



**Contents**



## 1. Need to review azo dye detoxification for industrial and environmental security

Since ancient civilization the dyes have been one of the integral components of socio-economic fabric of our societies. Though use of dyes is known since 2000 BC, the synthetic dyes have become an integral component of present day economies. Currently, synthetic dyes are the foundation of several industries like textile, pharmaceuticals, food and cosmetics owing to their versatile colors, ease in preparation and low costs (Saratale et al., 2011). Out of ~900,000 metric tons of dye produced annually (Carmen and Daniela, 2012), >70% belong to azo group (Balapure et al., 2015). According to an estimate, a significant proportion of industrial waste (17–20%) is comprised of dye effluents (Kant, 2012), with up to 50% of annual dye production reaching environment either directly as effluent or due to loss occurred during dying process (Carmen and Daniela, 2012). With countries of the Indian subcontinent, China and European Union together hosting ~70% of the world's dyeing industries (Ghaly et al., 2013), it is an environmental concern for ~50% of world's population which is residing in these countries.

Chemical dyes, being an integral component of several industries are irreplaceable. However, with such increasing reliance of industries on dyes, the severe negative impacts of dye effluents on environmental and human health have also become a matter of concern. The immediate toxic impact of dyes and degraded products on different living organisms (aquatic and terrestrial), and human being have been demonstrated (Copaciu et al., 2013; Puvaneswari et al., 2006; Umbuzeiro et al., 2005). Due to their xenobiotic and recalcitrant nature, azo dyes pose long-term challenge for the structure and function of different ecosystems. Although these ecosystems have natural remediation potential to alter the dyes but microbial and physico-chemical factors involved in degradation of these compounds may not always yield non-toxic or less toxic metabolites (Brown and Vito, 1993; Levine, 1991). In fact, in certain conditions, these environmental processes lead to conversion of non-toxic dyes into toxic metabolites (Gottlieb et al., 2003). Furthermore, microenvironment in mammalian body such as microflora of skin or gut ecosystem converts certain nontoxic dyes into toxic carcinogenic metabolites (Platzek et al., 1999). However, in any ecosystem, production of toxic metabolites is a result of interactions of microbes and dyes in the background of various environmental processes (Gottlieb et al., 2003).

Realizing the toxic potential of dye effluents, the ecological concern in growing economies becomes even more severe due to the indulgence of informal sectors in dye industry and the relaxed environmental policy frameworks or poor implementation of existing policies. For example, in most countries which are hub of dye industries, the dyes are envisaged only as a colored polluter neglecting their grave ecotoxic potentials (Ghaly et al., 2013). In fact, EU has enlisted 24 dye metabolites (aromatic amines) as toxic compounds and prohibited their use in industries (ETAD, 2008). Furthermore, efforts are also being made to develop remediation techniques for dyes and their metabolites. Therefore, the environmental management of dye effluents represents a major global thrust towards protection of biodiversity and health of the ecosystem (Brüschweiler et al., 2014; SCCNFP, 2002; Schneider et al., 2004).

Development of ecofriendly cost-effective methods which can address limitations of existing physico-chemical methods (viz. high cost, energy requirements, low environmental efficacy and generation of concentrated toxic sludge) is a global priority. Though physico-chemical methods are efficient in decolourization of azo dyes (Forgacs et al., 2004; Mu et al., 2009; Robinson et al., 2001), their efficacy to detoxify is still debatable. As microbial technologies