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Role Of Bacteria And Their Enzymes In Degradation Of Azo Dyes: A Review

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Abstract

The azo dyes are aromatic compounds containing azo (–N=N–) groups enabling them to be potent in absorbing visible spectrum light. These are considered to be electron-deficient toxic effluents due to the non-biodegradability function allowed through azo linking bonds. The azo bonds make the concerned dye resistant for preventing its degradation by enzymes produced by microorganisms. The most potent enzyme till now found for azo dye reduction is a group of reductase enzyme called azoreductase that facilitate the reaction using some suitable cofactors. Several microorganisms, especially the bacteria are readily used for successful azoreductase enzymes activity in azo dye decolourization. These enzymes are mostly isolated from bacterial cells and are found to be highly effective in case of partial or complete removal of azo dyes. Thus, the reason for the current review relies on a comprehensive systematization of various bacteria those are responsible for production of azoreductase enzymes and their application in azo dye decolourization. This review also compiles different bacterial enzymes responsible for degradation of the toxic azo dyes.

Keywords: Bacteria, azo dyes, biologically induced azo dye degradation and azoreductase

INTRODUCTION

Textile industrial waste is one of the prime dye pollutant sources, maximum of which is due to production of several commercial natural or synthetic dyes (Ong et al., 2010). More than 8000 artificial chemical compounds are used in dye formation techniques (Bhatia et al. 2017). On an average 10,000 chemically produced synthetic dyes are firmly with yearly production rate of 7×10^5 metric tons (Robinson et al., 2001; Khataee and Kasiri 2010). Dyes are critical industrial colouring agents those are mostly organic or inorganic in chemical composition with permanent colour producing capacity on to the applied fibers and are resistant in terms of colour fading with application of any chemicals, water or any light intensity, even to the microbial application also (Rai et al., 2005). The azo dyes (Fig.1) are basically included within the class of aromatic compounds with–N=N– groups (Zollinger, 1991) enabling them to be potent in absorbing visible spectrum light (Chang et al., 2000). In accordance with IUPAC classification system, most of the azo dyes are derivatives of compounds are derived from diazine with incorporated substitution in form of hydrocarbyl or diphenyldiazene or

azobenzene groups that are interlinked with the phenyl/naphthyl rings (Bell et al., 2000; Chung, 2016). These dyes along with some of the nitro-aromatic compounds utilised in colouring industries are regarded as potent xenobiotic agents.

Structurally these are categorized depending upon the available azo bond produced like as in monoazo, diazo, triazo and so on. Some of the prominent azo dyes are Acid blue 113, Reactive Black 5, Reactive Red 141, Reactive Red 198, Reactive Red 141, Reactive Blue 171, Congo red, Direct Brown MR, Methyl Red, Acid Orange 6, Acid Orange 52 and Acid Orange 7 etc.). Disposal of such dyes to surrounding causes serious hazardous condition with heavier impact on concerned living biota (Wijetunga et al., 2010). Industrialization has been the major cause for introduction of azo dye residues into water bodies. These toxic ions which being recalcitrant in nature remains within the water bodies and gets in food chain causing negative health issues.

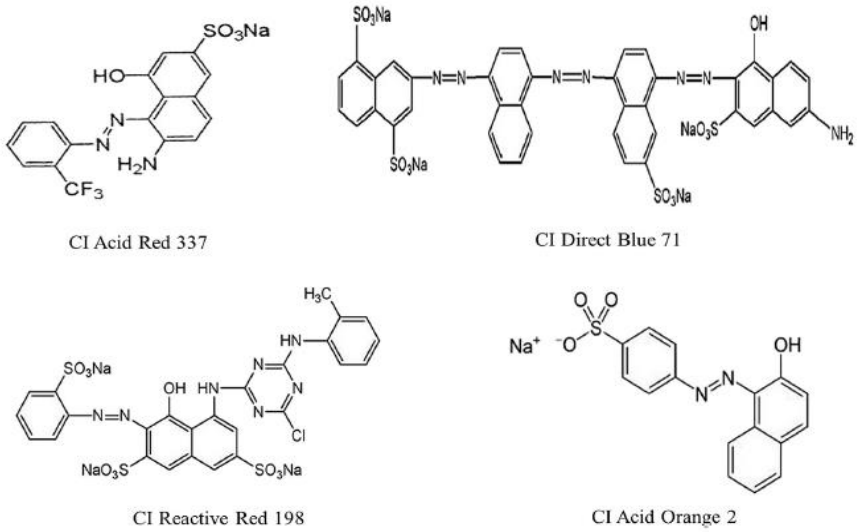

Fig. 1 Structures of some azo dyes (Singh et al., 2015)

Many norms have been set by different pollution control bodies all across the world for limiting the disposal of toxic metals in industrial wastewater. However, the lack of adequate technology to remove such a micro pollutant from the waste water is yet another issue in this regard. This issue requires a substitute, biologically influenced, eco-friendly approach to have sustainable and balanced environmental biological factors by reducing any toxic pollutant generation or accumulation (Al-Hoqani et al., 2021).

Most of the textile dyes are carcinogenic, which when accumulated in body, leads to alteration in several physiological and biological functions (Rawat et al. 2016). On an average around 2.8×10^5 tons/annum of industrial effluent dyes are dumped within water bodies making the concerned environment unfavourable (Jin et al., 2007; Wang et al., 2020). Due to complex aromatic molecular structure, synthetic dyes are highly stable and resistant to degradation. So, dye effluents are extremely toxic to plants, both aquatic fauna and flora, including human beings.

Treatment of harmful dye effluent discharged from textile industry is very important for environment as well as human health. Several methods have been reported to be widely used for degradation of dyes: Physical, chemical and biological treatment either individually or in combination (Lu et al., 2019). But these methods remain lagging due to lower effects in terms of either efficacy or economic value or impact on environment. The traditional remediation methods are insufficient, as non-ionic dyes do not ionize in aqueous form, and produce a large amount of sludge which requires further safe dumping (Maier *et al*., 2004). This has paved the path to utilize natural resources for remediation process from environment. Microbial mediated enzymatic degradation and reduction of azo dyes is one of available forms of bioremediation that not only successfully cleaves the azo bonds but also prevents the further sludge formation (Ngo and Tischler, 2022). The toxic nature of azo dyes and several intermediate products before and after microbial treatment has been studied by several researchers using plants, algae and microorganisms (Verma et al., 2008; Samuel et al., 2010; Telke et al., 2012; Jairajpuri et al., 2016; Ngo and Tischler, 2022).

BIOLOGICAL DEGRADATION OF AZO DYES USING BACTERIA

The biological degradation methods are considered as environment friendly, as they can mineralise organic contaminants without yielding secondary toxic sludge (Jirasripongpun et al., 2007). Toxic pollutants removal by microorganisms is less time-consuming process, with higher absorption rate and greater bioavailability. Among the methods of dye degradation, the bacterial azo dyes degradation process that occurs due to the activities of certain bacterial enzymes is way superior to normal physical or chemical or both physical and chemical combined methods. It is due to some of the remarkable benefits like ecologically feasibility, cost effectiveness, minimal sludge formation, reduced time requirement in processing of the entire process, biocompatibility with the media and minimal water utilisation for entire azo dye decolourization process to be completed (Dellamatrice et al., 2017; El-Borm et al., 2020; Ali et al., 2020). This method has gained popularity due to its efficient and selective nature (Sun et al., 2019) in degradation of toxic metal ions from large volumes of wastewater generated from industrial infrastructure. This review is a compilation of all the available enzymatic reactions from microbial sources, for biological degradation of these toxic azo dyes. These enzymes are mostly isolated from bacterial cells and enzymatic reactions are found to be highly effective in case of partial or complete removal of azo dyes (Table 1).

Table 1 Bacterial enzyme induced azo dye reduction

SI. No.	Name of Dyes	Bacteria	Mechanism	References
1.	Reactive Red 120 dye and Reactive Orange 96 dye	*Desulfovibrio desulfuricans*	Oxidative reaction	Yoo et al., 2000
2.	Reactive Red 22 dye	*Pseudomonas luteola*	Azoreductase reactions	Chang and Lin, 2000
3.	Reactive Orange 96 dye	Sulfate reducing bacteria	extracellular reduction reaction	Yoo et al., 2001
4.	Remazol Black B dye	*Paenibacillus azoreducens* sp. nov	Azoreductase reactions	Meehan et al., 2001
5.	Azo dye and Triphenylmethane Dyes	*Citrobacter* sp.	Reductive reactions	An et al., 2002
6.	Methyl Red dye	*Enterobacter agglomerans*	Reductive reactions	Keharia et.al., 2003
7.	Red RBN dye	*Aeromonas hydrophila*	Azoreductase reactions	Chen et al., 2003
8.	Acid Orange 6 dye, Acid Orange 52 dye and Acid Orange 7 dye	*Shewanella* sps	Reductive reactions	Yemashova et al., 2004
9.	Reactive Blue 172	*Pseudomonas aeruginosa* NBAR12	Oxidative and reductive reactions	Bhatt et al., 2005
10.	Reactive Brilliant Red dye	*Rhodopseudomonas palustris* AS1.2352	Azoreductase reactions	Liu et al., 2006
11.	Acid Red 97 dye, Acid Red 119 dye, Reactive Red 120 dye, Acid Red 88 dye and Acid Blue 113 dye	Bacterial consortium *Bacillus cereus, Stenotrophomonas acidaminiphila, Pseudomonas putida* and *Pseudomonas fluorescens*	Reductive reactions	Khehra et al., 2006
12.	Red BLI dye	*Pseudomonas* sp. SUK1	aminopyrine N-demethylase and NADH-DCIP reductase reactions.	Kalyani et.al, 2007

13.	Direct Blue-15 dye	Bacterial consortium *Alcaligenes faecalis, Bacillus subtilis, Bacillus thuringiensis, Sphingomonas sp.* EBD and *Enterobacter cancerogenus*	Reductive reactions	Kumar et al., 2007
14.	Navy blue 3G dye	*Brevibacillus laterosporus* MTCC2298	Azoreductase reactions	Jirasripongpun et al., 2007
15.	Acid Red GR dye	*Shewanella decolorationis* S12	Azoreductase reactions	Xu et al., 2007
16.	Acid blue 113 dye	*Bacillus subtilis*	Azoreductase reactions	Gurulakshmi et al., 2008
17.	Reactive Red 141 dye	*Rhizobium radiobacter* MTCC 8161	Oxidative and reductive reaction	Telke et al., 2008
18.	Navy Blue HE2R	*Exiguobacterium sp.* RD3	Oxidative and reductive reaction	Dhanve et al., 2008
19.	Disperse Blue 79 dye and Acid Orange 10 dye	*Bacillus fusiformis* KMK 5	Azoreductase reactions	Kolekar et.al, 2008
20.	Reactive Red 2 dye	*Pseudomonas* sp. SUK1	Oxidative and reductive reaction	Kalyani et al., 2008
21.	Reactive Yellow 84 dye, Reactive Red 198 dye, Reactive Red 141 dye, Reactive Black 5 dye and Reactive Blue 171dye	*Aeromonas hydrophila*	Reductive reaction	Hsueh et al., 2009
22.	Azo dyes such as Methyl Red, Orange G, Orange II, Direct Blue 15	*Lactobacillus acidophilus* and *Lactobacillus fermentum*	Lactase reactions	Chen et al., 2009a
23.	Reactive Red 141 dye	*Aeromonas hydrophila*	Azoreductase reactions	Chen et al., 2009b
24.	Reactive Orange 16 dye	*Bacillus* sp.	Azoreductase reactions	Telke et al., 2009a
25.	Direct Brown MR dye	*Acinetobacter calcoaceticus* NCIM 2890	Oxidative and reductive	Ghodake et al., 2009
26.	Reactive Green 19 A dye	*Micrococcus glutamicus* NCIM 2168	Oxidative and reductive reactions	Saratale et al., 2009
27.	Reactive Black 5 dye	*Enterobacter* sp. EC3	Reductive reactions	Wang et al., 2009
28.	Congo Red dye	*Bacillus* sp. ACT2	Reductive reactions	Gopinath et al., 2009
29.	Direct Black 38 dye	*Enterococcus gallinarum*	Azoreductase reactions	Bafana et al., 2009
30	Direct Blue 71 dye	*Escherichia coli* JM109 (pGEX-AZR)	Reductive reaction	Jin et al., 2009
31.	Congo red dye	*Pseudomonas* sp. SU-EBT	Oxidative reaction	Telke et al., 2009b

32.	Golden Yellow HER dye	*Brevibacillus laterosporus* MTCC 2298	Oxidative and reductive reaction	Gomare et al., 2009
33.	Reactive Blue 13 dye	*Pseudomonas* sp.	Azoreductase reactions	Lin et al., 2010
34.	Remazol Orange dye	*Pseudomonas aeruginosa*	Reductive reaction	Sarayu and Sandhya, 2010
35.	Green HE4BD dye	Bacterial consortium *Miccrococcus glutamicus* and *Proteus vulgaris*	Azoreductase reactions	Saratale et al. 2010
36	Direct Red 5B dye	*Shingobacterium* sp.	Reductive reaction	Tamboli et al., 2010
37.	Acid Red dye	*Acinetobacter radioresistens*	Azoreductase reactions	Ramya et al., 2010
38.	Reactive Blue 160 dye, Reactive Red 198 dye and Reactive Black 5 dye	*Staphylococcus gallinarum*, *Exiguobacterium acetylicum*, *Exiguobacterium indicum*	Azoreductase reactions	Chen et al., 2011
39.	Orange II dye, Sudan III dye	*Staphylococcus aureus*	Azoreductase reactions	Pan et al., 2011
40.	Red 2G dye	*Bacillus megaterium*	Azoreductase reactions	Khan, 2011
41.	Reactive Red 195 dye	*Rhodopseudomonas palustris*	Azoreductase reactions	Celik et al., 2012
42.	Reactive Red BL dye	*Alcaligenes* sp. AA09	Azoreductase reactions	Pandey and Dubey, 2012
43.	Methyl Red dye	*Bacillus subtilis* ORB 7106	Azoreductase reactions	Leelakriangsak and Borisut, 2012
44.	RY107 dye	*Brevibacterium* sp. strain VN-15	Azoreductase reactions	Franciscon et al., 2012
45.	Congo Red dye	*Proteus* sp.	Azoreductase reactions	Perumal et al., 2012
46.	Reactive Red 141 dye	*Bacillus lentus* BI377	Azoreductase reactions	Oturkar et al., 2013
47.	Reactive Red 195	*Bacillus* sp. ARd, *Pseudomonas* sp. ARa, *Bacillus* sp. ARc and *Ochrobactrum* sp. ARf	Dye-decolorizing peroxidases reactions	Khan et al., 2014
48.	Methyl Red dye	*Rhodococcus opacus*	Azoreductase reactions	Qi et al., 2016
49.	Congo Red dye	*Micrococcus luteus* 24M	Azoreductase reactions	Ito et al., 2018
50.	Congo Red dye	*Aliiglaciecola lipolytica*	Laccase reactions	Wang et al., 2020
51.	Methyl Red dye	*Kocuria indica* DP-K7	Reductive reaction	Kumaran et al., 2020
52.	Methyl Red dye	*Rhodococcus* sp. UCC 0008 and UCC 0016	Reductive reaction	Maniyam et al., 2020
53.	Novacron Red dye	*Bacillus firmus* H4, *Bacillus filamentosus* T13,	Azoreductase reaction	Guembri et al., 2021

		Bacillus subterraneus A36		
54.	Methyl Red dye and Brilliant Black dye	*Arthrobacter bambusae* DP-A9, *Leifsonia shinshuensis* DP-L11, *Dermacoccus nishinomiyaensis* DP-D10 and *Paraburkholderia* sp. DP-P12	Laccase reactions	Kumaran et al., 2022

BACTERIAL ENZYMES INVOLVED IN AZO DYE DEGRADATION

The azo dyes degradation process as includes microbial mediated enzymatic reactions was found to be better one. However, the efficacy of microbial mediated azo dye decolourization is greatly affected by certain external and internal factors like temperature, pH, microbial enzyme production rate, adaptability of the concerned bacteria etc (Pandey et al., 2007). Different types of microbial enzymes retain different types of mechanism for breakdown of the desired azo bonds (Saratale et al., 2011). The bacterial mediated azo dye degradation is facilitated by mainly two broad enzyme groups, namely Laccases enzyme and Azoreductases enzyme (Singh et al., 2015). Although, the most potent bacterial enzyme till now found for azo dye reduction is azoreductase (Misal et al., 2011; Chacko and Subramaniam, 2011; Saratale et al., 2011). Besides, certain other enzymes are also found to be potent in azo dye degradation and decolourization, for example Lignin peroxidase enzyme, Manganese peroxidase enzyme and Polyphenol oxidase enzyme. The degradation of azo dyes can be facilitated by both aerobic and anaerobic conditions (Khehra et al., 2005).

Azoreductase Enzyme (EC 1.7.1.6)

The azoreductase enzymes are the prime enzymes, secreted specially by microorganisms and are involved actively in azo dye degradation through bond cleavage (Pandey et al., 2007; Ngo and Tischler, 2022). The functionality of azoreductase enzyme relies greatly within the activity of reducing agents (FADH and NADPH), those are present during the reactions (dos-Santos et al., 2007; Van and Cervantes, 2009). Many of the bacterial groups with this enzyme are being explored for this reason, some of which include *Bacillus* sp. OY1-2, *Escherichia coli*, *Staphylococcus aureus*, *Xenophilus azovorans* and *Enterococcus faecalis* (Suzuki et al., 2001; Blumel et al., 2002; Bin et al., 2004; Chen et al., 2005). The intracellular azoreductase enzyme efficacy for azo dye decolourization is a little complicated due to the concerned dye structural complexity and polarity difference (Mota et al., 2021).

As most of the azo dyes are basically with larger molecular weight and contain sulphonate groups; hence, it is quite unmanageable for these dyes to move across through the bacterial membrane (Kumaran et al., 2020; Guembri et al., 2021). Due to this reason most of the azo dye reduction mechanisms involve enzyme mediated shuttle arrangements (Ramalho et al., 2002). In the technique of anaerobic mediated bacterial decolourization of azo dyes, the focus is on breakage of the azo bonds facilitated by azoreductase enzyme followed by redox mediator induced electron shuttle system that revolves around inner azoreductase and extracellular azo dye to produce the corresponding amine groups (McMullan et al., 2001; Ramalho et al., 2002; Chacko and Subramaniam, 2011). The entire reaction is being facilitated only in presence of certain reducing factors such as NADH or FADH (dos-Santos et al., 2007; Van and Cervantes, 2009) and is carried out through two steps, each of which leads with transfer of two electrons (Chang et al., 2000). The azoreductase enzymes are categorized and differentiated as flavin dependant (Chen et al., 2004; Chen et al., 2005) or flavin independent ones (Blumel et al., 2002; Blumel and Stolz, 2003). The prior one is further classified depending upon the use of different types of reducing agents, such as NADH only (Chen et al., 2004), NADPH only (Chen et al., 2005) or NADH and NADPH both (Wang et al., 2007).

This azo dye decolourization results in production of toxic amine groups those are the unstable intermediates and are further reduced to simpler forms either in presence or absence of oxygen by the same microorganisms (Joshi et al., 2010; Kumaran et al., 2020; Guembri et al., 2021). The efficacy of this enzyme in degrading azo dyes is directly proportional to its substrate specificity (Singh et al., 2015).

Laccase Enzyme (EC 1.10.3.2)

Another vital enzyme that is majorly used in azo dye decolourization is Laccase enzyme (Birhanli and Yesilada, 2006). It is one of the multicopper oxidase protein enzymes representing the copper containing polyphenol oxidases family. This enzyme is also known as multicopper oxidases (Arora and Sharma, 2010; Giardina et al., 2010). The larger scale utilisation of these enzymes has been extensively studied by several researchers (Kirby et al., 2000; Novotny et al., 2004). Though maximum percentage of laccase enzymes are being biosynthesized and extracted either from plant origin or from white-rot fungi origin; a remarkable amount is also being biosynthesized and extracted from bacterial groups (Gianfreda et al., 1999; Claus, 2003). The major mechanism involved in laccase enzyme activity during azo dye decolourisation is the biological oxidation of particular groups of phenolic and nonphenolic substitutes through utilisation of a specific type of electron acceptor, i.e., the molecular oxygen (Sharma et al., 2007). As these enzymes are weaker in substrate specificity, hence are mostly used in decolourization or degradation of a broad-spectrum azo dyes (De'Souza et al., 2006). The most affecting targets for laccase enzymes are the phenolic groups. The specific mechanism involved in laccase enzyme regulated azo dye decolourization and degradation is the oxidation of the targeted phenol rings through use of one electron for production of phenoxy radical (Peralta-Zamora et al., 2003; Blanquez et al., 2004; Dellamatrice et al., 2017; El-Borm et al., 2020; Ali et al., 2020). This phenoxy radical is then again oxidized through the same laccase enzyme to generate carbonium ion. This is so called as the entire created charge is localized on the specific carbon atom within the phenol ring that is having the azo bond. As the water molecule induced nucleophilic interaction generates 4 -sulfophenyldiazene along with benzoquinone; the 4 - Sulfophenyldiazene is oxidized to produce phenyldiazene radical due to its instability in the presence of oxygen molecules. In the process, the benzoquinone also loses nitrogen molecule to be converted into sulfophenyl radical that is attacked by molecular oxygen to generate 4 sulfophenylhydroperoxide (Singh et al., 2015).

Peroxidases Enzyme (EC 1.11.1.x)

These enzymes are kind of hemoproteins that functions mostly in comportment of hydrogen peroxide (H_2O_2) (Duran et al., 2002). These enzymes are generally biosynthesized within wide range of organisms. However, these are widely grouped into different categories in accordance with their biological source of development, chemical structure and substrate specificity (Koua et al., 2009). These are di-heme cytchrome-c peroxidase, haloperoxidase, non-animal peroxidase, animal peroxidase, DyP-type peroxidase and catalase.
These enzymes are having different substrate specific binding sites namely heme d, heme c and tryptophan residue (Gumiero et al., 2010). Mostly these enzymes initiate and facilitate the complete degradation and decolourization of textile dyes. In a study, orange G and sunset yellow dye degradation and decolourization was achieved by application of hydrogen peroxide in the presence of chloroperoxidase enzyme (Zhang et al., 2012). This enzyme is highly effective in degradation of aromatic amines and phenolic compounds from liquid wastes. Even the horseradish peroxidase enzyme was found to achieve 59% of degradation of remazol turquoise blue G dye, 94% of degradation of lanaset blue 2R dye and 52% of degradation of textile effluents (De'Souza et al., 2007; Mota et al., 2021).

Polyphenol oxidase (PPO) Enzyme (EC 1.14.18.1)

Polyphenol oxidase is another vital enzyme used for azo dye degradation frequently, containing 4 copper atoms per enzyme molecule with three binding sites, out of which two are for aromatic compounds and the other one is for oxygen molecule. Polyphenol oxidase enzyme accelerates the hydroxylation reaction for production of o-diphenol from monophenols. Even this series of reaction continues with conversion of o-diphenols to o-quinones (Mota et al., 2021; Dellamatrice et al., 2017). As tyrosine with single phenolic ring is easily oxidized in the comportment of (PPO) Polyphenol oxidase enzyme to form o-quinone; hence the enzyme is also known as tyrosinase (Solis et al., 2012; Kumaran et al., 2020; Guembri et al., 2021).
Polyphenol oxidase enzymes are considered as oxidoreductive enzyme and are capable of degradation and removal of aromatic toxicants from various contaminated sites including the azo dyes. This enzyme is having a higher and quite broader range of substrate specificity and hence is able to degrade maximum amount of azo dyes even at a very lower concentration (Husain and Jan, 2000).
As discussed briefly, the different types of bacterial enzymes those contribute towards azo dye degradation are azoreductase enzymes, polyphenol oxidase enzymes, peroxidase enzymes and laccase enzymes (Mota et al., 2021). Due to structural complexity, substrate specificity, pH, temperature sensitivity and some of the related

internal and external factors, the degradation rate of azo dyes through utilisation of the selected bacterial strains and their enzymes may vary greatly (Kumaran et al., 2020; Guembri et al., 2021).

RECENT ADVANCEMENTS

The recent advancement in treatment of azo dyes is use of bacterial fuel cell for dye degradation. The bacterial fuel cells along with specific bacterial cells can also facilitate not only bioelectricity generation, but also enhance the degradation of several nitrogenous, sulphur related toxic pollutant removes from the waste water along with the azo dyes along. These bacterial cells also help in microbial mediated electrosynthesis of related by products and can also function as active biosensor for easy detection of pollutants from waste water system from different sources (Wang et al., 2020; Kumaran et al., 2022). However, the biodegradation of each kind requires variable bacterial fuel cell structural design, varying types of electrode selection, mechanism set up at optimized condition. These factors would ease the method processing in a smoother way (Bakhshian et al., 2011; Hou et al., 2012). The entire process requires proper set up conditions with accurate percentage of substrate concentration followed by type of microorganisms to be used with constant maintenance of medium pH, temperature etc. The methodology optimization is a greater challenge for large scale processing as it has monetary constrain followed by consistency of the given methodology. This would be resolved by utilization of organic compounds derived from easily available source to be treated as substrate. Furthermore, the formation and disposal rate of such waste water is the maximum and are derived from different types of sources. Some of the bacteria those are used frequently in microbial fuel cells for degradation of azo dyes are *Shewanella oneidensis* (Fernando et al., 2012), *Proteus hauseri* (Chen et al., 2011). The azo dye Acid Orange 7 was successfully degraded by *Shewanella oneidensis* through utilisation within a microbial fuel cell. Similarly Reactive Blue 160 dye was successfully degraded by *Proteus hauseri* through utilisation within a microbial fuel cell.

CONCLUSION

The azo dyes are structurally larger molecules with aromatic compound link ups and azo bond additions that make them way more advances and resistance to degradation than compared to normal synthetic dyes or textile dyes. These are widely utilized in food industries, tannery industries, textile industries, pharmaceutical industries, cosmetic industries and many more, creating maximum pollution and toxicity and generating huge wastewater system. In order to get rid of the detrimental consequences of these toxic metal ions and dye, several techniques (chemical, physical, biological) are employed individually or in combinations. But the potency of all the available systems can decline or reduced may be due to inefficiency, inadequate activity of dye degradation or reduced quantity and quality of degraded product. This opens the ways for utilization of natural resources for bioremediation of waste water. The sustainable utilization of bacterial consortium individually or with some other sources like plant species can mediate the complete removal of available toxic sources without production of any associated sludges. Moreover, the waste water, as consisting of several organic compounds, can act as suitable substrate for bacterial bioremediation to degrade all the toxic pollutants. The azo dye emitted or mixed toxicity within the wastewater system and the corresponding pollution can be reduced greatly through the utilisation of bacterial remediation technology that includes the application of bacterial enzyme systems in a conjugated manner.

This review compiles the available literatures and studies on bacterial enzyme mediated biodegradation of azo dyes through a low cost and highly potent mechanism for further enlightening future researchers on this field.

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Authors Contribution Malvika Singh has been involved in study conception, design and drafting the manuscript.
Seema Bhadauria has made substantial contributions to study conception, design and in writing final draft of the manuscript.

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REFERENCES

1. Al-Hoqani, M., Zafar, M., Al Musharafi, SK., Mahanty, B. and Behera, S.K. (2021). COD Fractionation and Solubility Assessment of Sonicated Waste-activated Sludge. *Environ. Qual. Manag*., 1 – 8.
2. Ali, M.Y., Hassan, G.M., Hassan, A.M.S., Mohamed, Z.A. and Ramadan, M.F. (2020). In vivo genotoxicity assessment of sunset yellow and sodium benzoate in female rats. *Drug Chem. Toxicol*., 43, 504 – 513.
3. An, S.Y., Min, S.K., Cha, I.H., Choi, YL., Cho, Y.S., Kim, C.H. and Lee, Y.C. (2002). Decolorization of Triphenylmethane and Azo Dyes by *Citrobacter* sp. *Biotechnol. Lett.*, 24,1037 – 1040.
4. Arora, D.S. and Sharma, R.K. (2010). Ligninolytic fungal laccases and their biotechnological applications. *Appl. Biochem. Biotechnol*., 160, 1760 – 1788.
5. Bafana, A., Chakrabarti, T., Muthal, P. and Kanade, G. (2009). Detoxification of Benzidine-Based Azo Dye by *E. gallinarum*: Time-Course Study. *Ecotoxicol. Environ. Safety*, 72, 960.
6. Bakhshian, S., Kariminia, H.R. and Roshandel, R. (2011). Bioelectricity generation enhancement in a dual chamber microbial fuel cell under cathodic enzyme catalyzed dye decolorization. *Bioresour Technol*, 102, 6761 – 6765.
7. Bell, J., Plumb, J.J., Buckley, C.A. and Stuckey, D.C. (2000). Treatment and Decolorization of Dyes in an Anaerobic Baffled Reactor. *J. Environ. Eng*., 126, 1026 – 1032.
8. Bhatia, D., Sharma, N.R., Singh, J and Kanwar, R.S. (2017). Biological methods for textile dye removal from wastewater: a review. *Crit. Rev. Environ. Sci. Technol.*, 47(19), 1836 – 1876.
9. Bhatt, N., Patel, K.C., Keharia, H. and Madamwar, D. (2005). Decolorization of diazo-dye Reactive Blue 172 by *Pseudomonas aeruginosa* NBAR12. *J. Basic Microbiol.*, 45(6), 407 - 418.
10. Bin, Y., Jiti, Z., Jing, W., Cuihong, D., Hongman, H., Zhiyong, S., and Yongming, B. (2004). Expression and characteristics of the gene encoding azoreductase from *Rhodobacter sphaeroides* AS1.1737. *FEMS Microbiol. Lett*., 236, 129 – 136.
11. Birhanli, E. and Yesilada, O. (2006). Increased production of laccase by pellets of *Funalia trogii* ATCC 200800 and *Trametes versicolor* ATCC 200801 in repeated-batch mode. *Enzyme Microb. Technol*., 39, 1286 – 1293.
12. Blanquez, P., Casas, N., Font, X., Gabarrell, X., Sarra, M., Caminal, G. and Vicent, T. (2004). Mechanism of textile metal dye biotransformation by *Trametes versicolor*. *J. Water Res*., 38, 2166 – 2172.
13. Blumel, S. and Stolz, A. (2003). Cloning and characterization of the gene coding for the aerobic azoreductase from *Pigmentiphaga kullae* K24. *Appl. Microbiol. Biotechnol*., 62, 186 – 190.
14. Blumel, S., Knackmuss, H.J. and Stolz, A. (2002). Molecular cloning and characterization of the gene coding for the aerobic azoreductase from *Xenophilus azovorans* KF46F. *Appl. Microbiol. Biotechnol.*, 68, 3948 – 3955.
15. Celik, L., Öztürk, A. and Abdullah, M.I. (2012). Biodegradation of Reactive Red 195 azo dye by the bacterium *Rhodopseudomonas palustris*. *Afr. J. Microbiol, Res*., 6, 120 – 126.
16. Chacko, J.T. and Subramaniam, K. (2011). Enzymatic degradation of azo dyes: a review, *Int. J. Environ. Sci*., 1, 1250 – 1260.
17. Chang, J.S. and Lin, Y.C. (2000). Fed-Batch Bioreactor Strategies for Microbial Decolorization of Azo Dye using a *Pseudomonas luteola* Strain. *Biotechnol. Prog*., 16, 979 – 985.
18. Chen, B.Y., Hsueh, C.C., Chen, W.M. and Li, W.D. (2011). Exploring decolorization and halotolerance characteristics by indigenous acclimatized bacteria: chemical structure of azo dyes and dose–response assessment, *J. Taiwan. Inst. Chem. Eng*., 42, 816 – 825.
19. Chen, B.Y., Lin, K.W., Wang, Y.M. and Yen, C.Y. (2009b). Revealing Interactive Toxicity of Aromatic Amines to Azo Dye Decolorizer *Aeromonas hydrophila*. *J. Hazard. Mater*., 166, 187 – 194.
20. Chen, H., Hopper, S.L. and Cerniglia, C.E. (2005). Biochemical and molecular characterization of an azoreductase from *Staphylococcus aureus*, a tetrameric NADPH dependent flavoprotein. *Microbiology*, 151, 1433 – 1441.

21. Chen, H., Wang, R.F. and Cerniglia, C.E. (2004). Molecular cloning, overexpression, purification, and characterization of an aerobic FMN-dependent azoreductase from *Enterococcus faecalis*. *Protein Expr. Purif*., 34, 302 – 310.
22. Chen, H., Xu, H., Heinze, T.M. and Cerniglia, C.E. (2009a). Decolorization of Water and Oil soluble Azo Dyes by *Lactobacillus acidophilus* and *Lactobacillus fermentum*. *J. Ind. Microbiol. Biotechnol*., 36, 1459 – 1466.
23. Chen, K.C., Wu, J.Y., Liou, D.J. and Hwang, S.C.J. (2003). Decolorization of the Textile Dyes by Newly Isolated Bacterial Strains. *J. Biotechnol*., 101, 57 – 68.
24. Chung, K.T. (2016). Azo Dyes and Human Health: A Review, *J. Environ. Sci. Health Part C*, 34, 233 – 261.
25. Claus, H. (2003). Laccases and their occurrence in prokaryotes. *Arch. Microbiol*., 179, 145 – 150.
26. Dellamatrice, P.M., Silva-Stenico, M.E., Moraes, L.A.B.D., Fiore, M.F. and Monteiro, R.T.R. (2017). Degradation of textile dyes by cyanobacteria. *Braz. J. Microbiol.*, 48 (1), 25 – 31.
27. De'Souza, D.T., Tiwari, R., Sah, A.K. and Raghukumara, C. (2006). Enhanced production of laccase by a marine Fungus during treatment of colored effluents and synthetic dyes. *Enzyme Microb. Technol.*, 38, 504 – 511.
28. De'Souza, S.M.A.G.U., Forgiarini, E. and De'Souza, A.A.U. (2007). Toxicity of textile dyes and their degradation by the enzyme horseradish peroxidase (HRP). *J. Hazard. Mater*. 147, 1073 – 1078.
29. Dhanve, R.S., Shedbalkar, U.U. and Jadhav, J.P. (2008). Biodegradation of diazo reactive dye Navy blue HE2R (Reactive blue 172) by an isolated *Exiguobacterium* sp. RD3. *Biotechnol. Bioproc. E.*, 13**,** 53 – 60.
30. dos-Santos, A.B., Cervantes, F.J. and van Lier, J.B. (2007). Review paper on current technologies for decolourisation of textile wastewaters: perspectives for anaerobic biotechnology. *Bioresour. Technol*., 98 (12), 2369 – 2385.
31. Duran, N., Rosa, M.A., D'Annibale, A. and Gianfreda, L. (2002). Applications of laccases and tyrosinases (phenoloxidases) immobilized on different supports: A review. *Enzyme Microb. Technol*., 31, 907 – 931.
32. El-Borm, H.T., Badawy, G.M., Hassab El-Nabi, S., El-Sherif, W.A. and Atallah, M.N. (2020). Toxicity of sunset yellow FCF and tartrazine dyes on DNA and cell cycle of liver and kidneys of the chick embryo: The alleviative effects of curcumin. *Egypt. J. Zool.*, 74, 43 – 55.
33. Fernando, E., Keshavarz, T. and Kyazze, G. (2012). Enhanced bio-decolourisation of Acid Orange 7 by *Shewanella oneidensis* through co-metabolism in a microbial fuel cell. *Int. Biodeter. Biodegr*., 72, 1 – 9.
34. Franciscon, E., Grossman, M.J., Paschoal, J.A.R., Reyes, F.G.R. and Durrant, L.R. (2012). Decolorization and biodegradation of reactive sulfonated azo dyes by a newly isolated *Brevibacterium* sp. strain VN-15. *SpringerPlus*, 1, 1 – 37.
35. Ghodake, G., Jadhav, S., Dawkar, V. and Govindwar, S. (2009). Biodegradation of Diazo Dye Direct Brown MR by *Acinetobacter calcoaceticus* NCIM 2890, *Int. Biodeter. Biodegr*., 63, 433 – 439.
36. Gianfreda, L., Xu, F. and Bollag, J.M. (1999). Laccases: a useful group of oxidoreductive enzymes. *Bioremediation J*., 3, 1 – 26.
37. Giardina, P., Faraco, V., Pezzella, C., Piscitelli, A., Vanhulle, S. and Sannia, G. (2010). Laccases: a never-ending story. *Cell. Mol. Life Sci.*, 67 (3), 369 – 385.
38. Gomare, S.S. and Govindwar, S.P. (2009). *Brevibacillus laterosporus* MTCC 2298. A Potential Azo Dye Degrader. *J. Appl. Microbiol*., 106 (3), 993 – 1004.
39. Gopinath, K.P., Murugesan, S., Abraham, J. and Muthukumar, K. (2009). *Bacillus* sp. Mutant for Improved Biodegradation of Congo Red: Random Mutagenesis Approach. *Bioresour. Technol*., 100 (24), 6295 – 6300.
40. Guembri, M., Neifar, M., Saidi, M., Ferjani, R., Chouchane, H., Mosbah, A., Cherif, A., Saidi, N. and Ouzari, H.I. (2021). Decolorization of textile azo dye Novacron Red using bacterial monoculture and consortium: Response surface methodology optimization. *Water Environ. Res*., 93 (8), 1346 – 1360.
41. Gumiero, A., Murphy, E.J., Metcalfe, C.L., Moody, P.C.E. and Raven, E.L. (2010). An analysis of substrate binding interactions in the heme peroxidase enzymes: a structural perspective. *Arch. Biochem. Biophys*., 500, 13 – 20.
42. Gurulakshmi, M., Sudarmani, D.N.P. and Venba, R. (2008). Biodegradation of Leather Acid dye by *Bacillus subtilis*. *Adv. Biotech*., 7, 12 - 18.
43. Hou, B., Hua, Y. and Sun, J. (2012). Performance and microbial diversity of microbial fuel cells coupled with different cathode types during simultaneous azo dye decolorization and electricity generation. *Bioresour. Technol.*, 111, 105 – 110.
44. Hsueh, C.C., Chen, B.Y. and Yen, C.Y. (2009). Understanding effects of chemical structure on azo dye decolorization characteristics by *Aeromonas hydrophila*. *J. Hazard. Mater*., 167 (1-3), 995 – 1001.

45. Husain, Q. and Jan, U. (2000). Detoxification of phenol and aromatic amines from polluted waste water by using phenol oxidases. *J. Sci. Ind. Res.*, 59, 286 – 293.
46. Ito, T., Shimada, Y. and Suto, T. (2018). Potential use of bacteria collected from human hands for textile dye decolorization. *Water Resour. Ind*., 20, 46 – 53.
47. Jairajpuri, M., Raval, R. and Patel, K. (2016). Chromosomal aberrations in root meristems of *Allium cepa* L. induced by dyeing industrial effluent. *Int. j*. multidiscip. *res*. *dev*., 3 (6), 272 – 275.
48. Jin, R., Yang, H., Zhang, A., Wang, J. and Liu, G. (2009). Bioaugmentation on Decolorization of C.I. Direct Blue 71 by Using Genetically Engineered Strain *Escherichia coli* JM109 (pGEX-AZR). *J. Hazard. Mater.*, 163 (2-3), 1123 – 1128.
49. Jin, X.C., Liu, G.Q., Xu, Z.H. and Tao, W.Y. (2007). Decolourisation of a Dye Industry Effluent by *Aspergillus fumigatus* XC6. *Appl. Microbiol. Biotechnol*., 74, 239 – 243.
50. Jirasripongpun, K., Nasanit, R., Niruntasook, J. and Chotikasatian, B. (2007). Decolorization and Degradation of C.I. Reactive Red 195 by *Enterobacter* sp. *Thammasat Int. J. Sci. Technol*., 12, 6 – 11.
51. Joshi, S.M., Inamdar, S.A., Telke, A.A., Tamboli, D.P. and Govindwar, S.P. (2010). Exploring the potential of natural bacterial consortium to degrade mixture of dyes and textile effluent. *Int. Biodeter. Biodegr*., 64, 622– 628.
52. Kalyani, D.C., Patil, P.S., Jadhav, J.P. and Govindwar, S.P. (2007). Biodegradation of reactive textile dye Red BLI by an isolated bacterium *Pseudomonas* sp. SUK1. *Biores. Technol.*, 99 (11), 4635 – 4641.
53. Kalyani, D.C., Telke, A.A., Dhanve, R.S. and Jadhav, P. (2008). Ecofriendly Biodegradation and Detoxification of Reactive Red 2 Textile Dye by Newly Isolated *Pseudomonas* sp. SUK1. *J. Hazard. Mater.*, 163 (2-3), 735 – 742.
54. Keharia, H. and Madamwar, D. (2003). Bioremediation concepts for treatment of dye containing water: A review. *Indian J. Exp. Biol.*, 41 (9), 1068 – 1075.
55. Khan, J.A. (2011). Biodegradation of azo dye by moderately halotolerant *Bacillus megaterium* and study of enzyme azoreductase involved in degradation. *Adv. Biotechnol.*, 10, 21 – 27.
56. Khan, Z., Jain, K., Soni, A. and Madamwar, D. (2014). Microaerophilic degradation of sulphonated azo dye–Reactive Red 195 by bacterial consortium AR1 through co-metabolism. *Int. Biodeterior. Biodegrad*., 94, 167 – 175.
57. Khataee, A.R. and Kasiri, M.B. (2010). Photocatalytic degradation of organic dyes in the presence of nanostructured titanium dioxide: infuence of the chemical structure of dyes. *J. Mol. Catal. A: Chem*., 328(1), 8 – 26.
58. Khehra, M.S., Saini, H.S., Sharma, D.K., Chadha, B.S. and Chimni, S.S. (2005). Comparative studies on potential of consortium and constituent pure bacterial isolates to decolorize azo dyes. *Water Res.*, 39 (20), 5135 – 5141.
59. Khehra, M.S., Saini, H.S., Sharma, D.K., Chadha, B.S. and Chimni, S.S. (2006). Biodegradation of Azo Dye C.I. Acid Red 88 by an Anoxic–Aerobic Sequential Bioreactor. *Dyes and Pigments*, 70, 1 – 7.
60. Kirby, N., Marchant, R. and McMullan, G. (2000). Decolorization of synthetic textile dyes by *Phlebia tremellosa. FEMS Microbiol. Lett*., 188, 93 – 96.
61. Kolekar, Y.M., Pawar, S.P., Gawai, K.R., Lokhande, P.D., Shouche, Y.S. and Kodam, K.M. (2008). Decolorization and Degradation of Disperse Blue 79 and Acid Orange 10, by *Bacillus fusiformis* KMK5 Isolated from the Textile Dye Contaminated Soil. *Bioresour. Technol*., 99 (18), 8999 – 9003.
62. Koua, D., Cerutti, L., Falquet, L., Sigrist, C.J., Theiler, G., Hulo, N. and Dunand, C. (2009). PeroxiBase: a database with new tools for peroxidase family classification. *Nucleic Acids Res*. 37 (Database issue), D261 - D266.
63. Kumar, K., Devi, S.S., Krishnamurthi, K., Dutta, D. and Chakrabarti, T. (2007). Decolorization and Detoxification of Direct Blue-15 by a Bacterial Consortium. *Bioresour. Technol*., 98 (16), 3168 – 3171.
64. Kumaran, S., Ngo, A.C.R., Schultes, F., Saravanan, V.S. and Tischler, D. (2022). In vitro and in silico analysis of Brilliant Black degradation by *Actinobacteria* and a *Paraburkholderia* sp. *Genomics*, 114 (2), 110266.
65. Kumaran, S., Ngo, A.C.R., Schultes, F.P.J. and Tischler, D. (2020). Draft genome sequence of *Kocuria indica* DP-K7, a methyl red degrading actinobacterium. 3 Biotech, 10 (4), 175.
66. Leelakriangsak, M. and Borisut, S. (2012). Characterization of the decolorizing activity of azo dyes by *Bacillus subtilis* azoreductase AzoR1. *Songklankrin J. Sci. Technol*., 34, 509 – 516.
67. Lin, J., Zhang, X., Li, Z. and Lei, L. (2010). Biodegradation of Reactive Blue 13 in a Two-Stage Anaerobic / Aerobic Fluidized Beds System with a *Pseudomonas* sp. Isolate. *Bioresour. Technol*., 101 (1), 34 – 40.

68. Liu, G.F., Zhou, J.T., Wang, J., Song, Z.Y. and Qv, Y.Y. (2006). Bacterial Decolorization of Azo Dyes by *Rhodopseudomonas palustris*. *World J. Microbiol. Biotechnol*., 22, 1069 – 1074.
69. Lu, H., Wang, X., Zang, M., Zhou, J., Wang, J. and Guo, W. (2019). Degradation pathways and kinetics of anthraquinone compounds along with nitrate removal by a newly isolated *Rhodococcus pyridinivorans* GF3 under aerobic conditions. *Bioresour. Technol*., 285, 121336.
70. Maier, J., Kandelbauer, A., Erlacher, A., Cavaco-Paulo, A. and Gübitz, G.M. (2004). A new alkali-thermostable azoreductase from *Bacillus* sp. strain SF. *Appl. Environ. Microbiol*., 70 (2), 837 – 844.
71. Maniyam, M.N., Ibrahim, A.L. and Cass, A.E. (2020). Decolourization and biodegradation of azo dye methyl red by *Rhodococcus* strain UCC 0016. *Environ. Technol*., 41, 71 – 85.
72. McMullan, G., Meehan, C., Conneely, A., Kirby, N., Robinson, T. and Nigam, P. (2001). Microbial decolourisation and degradation of textile dyes. *Appl Microbiol Biotechnol.*, 56 (1-2), 81 – 87.
73. Meehan, C., Bjourson, A.J. and McMullan, G. (2001). *Paenibacillus azoreducens* sp. nov., a Synthetic Azo Dye Decolorizing Bacterium from Industrial Wastewater. *Int. J. Syst. Evol. Microbiol*., 51, 1681 – 1685.
74. Misal, S.A., Lingojwar, D.P., Shinde, R.M. and Gawai, K.R. (2011). Purification and characterization of azoreductase from alkaliphilic strain *Bacillus badius*. *Process Biochem*, 46, 1264 – 1269.
75. Mota, I.G.C., Neves, R.A.M.D., Nascimento, S.S.D.C., Maciel, B.L.L., Morais, A.H.D.A. and Passos, T.S. (2021). Artificial dyes: Health risks and the need for revision of international regulations. *Food Rev. Int*., 27, 1 – 16.
76. Ngo, A.C.R. and Tischler, D. (2022). Microbial Degradation of Azo Dyes: Approaches and Prospects for a Hazard-Free Conversion by Microorganisms. *Int. J. Environ. Res. Public Health*, 19 (8), 4740.
77. Novotny, C., Svobodova, K., Kasinath, A. and Erbanova, P. (2004). Biodegradation of synthetic dyes by *Irpex lacteus* under various growth conditions. *Int. Biodeterior. Biodegrad.*, 54, 215 – 223.
78. Ong, S., Uchiyama, K., Inadama, D., Ishida, Y. and Yamagiwa, K. (2010). Treatment of azo dye Acid Orange 7 containing wastewater using up-flow constructed wetland with and without supplementary aeration. *Bioresour. Technol*., 101 (23), 9049 – 9057.
79. Oturkar, C.C., Patole, M.S., Gawai, K.R. and Madamwar, D. (2013). Enzyme based cleavage strategy of *Bacillus lentus* BI377 in response to metabolism of azoic recalcitrant. *Bioresour. Technol*., 130, 360 – 365.
80. Pan, H., Feng, J., Cerniglia, C.E. and Chen, H. (2011). Effects of Orange II and Sudan III azo dyes and their metabolites on *Staphylococcus aureus*. *J. Ind. Microbiol. Biotechnol*., 38 (10), 1729 – 1738.
81. Pandey, A., Singh, P. and Iyengar, L. (2007). Bacterial decolorization and degradation of azo dyes. *Int. Biodeterior. Biodegrad*., 59, 73 – 84.
82. Pandey, A.K. and Dubey, V. (2012). Biodegradation of azo dye Reactive Red BL by *Alcaligenes* sp. AA09, *Int. J. Eng. Sci*., 1, 54 – 60.
83. Peralta-Zamora, P., Pereira, C.M., Tiburtius, E.R.L., Moraes, S.G., Rosa, M.A., Minussi, R.C. and Duran, N. (2003). Decolorization of reactive dyes by immobilized laccase. *Appl. Catal. B: Environ*., 42, 131 – 144.
84. Perumal, K., Malleswari, R.B., Catherin, A. and Sambanda-Moorthy, T.A. (2012). Decolorization of Congo Red dye by bacterial consortium isolated from dye contaminated soil, Paramakudi, Tamil Nadu. *J. Microbiol. Biotechnol. Res*., 2, 475 – 480.
85. Qi, J., Schlömann, M. and Tischler, D. (2016). Biochemical characterization of an azoreductase from *Rhodococcus opacus* 1CP possessing methyl red degradation ability. *J. Mol. Catal. B Enzym*,, 130, 9 – 17.
86. Rai, H., Bhattacharya, M., Singh, J., Bansal, T.K., Vats, P. and Banerjee, U.C. (2005). Removal of Dyes from the Effluent of Textile and Dyestuff Manufacturing Industry:A Review of Emerging Techniques with Reference to Biological Treatment. *Crit. Rev. Environ. Sci. Technol*., 35, 219 – 238.
87. Ramalho, P.A., Scholze, H., Cardoso, M.H., Ramalho, M.T. and Oliveira-Campos, A.M. (2002). Improved conditions for the aerobic reductive decolourisation of azo dyes by *Candida zeylanoides*. *Enzyme Microb. Technol*., 31, 848 – 854.
88. Ramya, M., Iyappan, S., Manju, A. and Jiffe, J.S. (2010). Biodegradation and decolorization of Acid Red by *Acinetobacter radioresistens. J. Bioremed. Biodegrad.*, 1, 105.
89. Rawat, D., Mishra, V. and Sharma, R.S. (2016). Detoxifcation of azo dyes in the context of environmental processes. *Chemosphere*, 155, 591 – 605.
90. Robinson, T., McMullan, G., Marchant, R. and Nigam, P. (2001). Remediation of dyes in textile effluent: a critical review on current treatment technologies with a proposed alternative. *Bioresour. Technol.*, 77 (3), 247 – 255.

91. Samuel, O.B., Osuala, F.I. and Odeigah, P.G.C. (2010). Cytogenotoxicity evaluation of two industrial effluents using *Allium cepa* assay. *Afr.* J. Environ. *Sci. Technol.*, 4 (1), 21 – 27.
92. Saratale, R.G., Saratale, G.D., Chang, J.S. and Govindwar, S.P. (2009). Ecofriendly degradation of sulfonated diazo dye C.I. Reactive Green 19A using *Micrococcus glutamicus* NCIM- 2168. *Bioresour. Technol*., 110 (17), 3897 - 3905.
93. Saratale, R.G., Saratale, G.D., Chang, J.S. and Govindwar, S.P. (2010). Decolorization and Biodegradation of Reactive Dyes and Dye Wastewater by a Developed Bacterial Consortium, *Biodegradation*, 21(6), 999 – 1015.
94. Saratale, R.G., Saratale, G.D., Chang, J.S. and Govindwar, S.P. (2011). Bacterial decolorization and degradation of azo dyes: a review. *J. Taiwan Inst. Chem. Eng*., 42, 138 – 157.
95. Sarayu, K. and Sandhya, S. (2010). Aerobic Biodegradation Pathway for Remazol Orange by *Pseudomonas aeruginosa*. *Appl. Biochem. Biotechnol*., 160 (4), 1241 - 1253.
96. Sharma, P., Goel, R. and Caplash, N. (2007). Bacterial laccases, *World J. Microbiol. Biotechno*l., 23, 823 - 832.
97. Singh, R.L., Singh, P.K. and Singh, R.P. (2015). Enzymatic decolorization and degradation of azo dyes-A review. *Int. Biodeterior. Biodegradation*, 104, 21 – 31.
98. Solis, M., Solis, A., Perez, H.I., Manjarrez, N. and Floresa, M. (2012). Microbial decolouration of azo dyes: A review. *Process Biochemistry*, 47, 1723 – 1748.
99. Sun, X., Huang, H., Zhu, Y., Yingying, D., Yao, L., Jiang, X. and Peng-Cheng, G. (2019). Adsorption of Pb2+ and Cd2+ onto *Spirulina platensis* harvested by polyacrylamide in single and binary solution systems. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 583, 123926.
100. Suzuki, Y., Yoda, T., Ruhul, A. and Sugiura, W. (2001). Molecular cloning and characterization of the gene encoding azoreductase from *Bacillus* sp. OY 1-2 isolated from soil. *J. Biol. Chem*, 276 (12), 9059 – 9065.
101. Tamboli, D.P., Kagalkar, A.N., Jadhav, M.U., Jadhav, J.P. and Govindwar, S.P. (2010). Production of polyhydroxyhexadecanoic acid by using waste biomass of *Sphingobacterium* sp. ATM generated after degradation of textile dye Direct Red 5B. *Bioresour. Technol.*, 101 (7), 2421 – 2427.
102. Telke, A.A., Kim, S.W. and Govindwar, S.P. (2012). Significant reduction in toxicity, BOD, and COD of textile dyes and textile industry effluent by a novel bacterium *Pseudomonas sp*. LBC1. *Folia Microbiologica*, 57 (2), 115 – 122.
103. Telke, A.A.D., Kalyani, C., Dawkar, V.V. and Govindwar, S.P. (2009a). Influence of Organic and Inorganic Compounds on Oxidoreductive Decolorization of Sulfonated Azo Dye C.I. Reactive Orange 16. *J. Hazard. Mater*., 172, 298 – 309.
104. Telke, A.A.D., Kalyani, C., Jadhav, U.U. and Govindwar, S.P. (2008). Kinetics and Mechanism of Reactive Red 141 Degradation by a Bacterial Isolate *Rhizobium radiobacter* MTCC 8161. *Acta Chim. Slov*, 55, 320 – 329.
105. Telke, A.A.D., Kalyani, C., Jadhav, U.U., Parshetti, G.K. and Govindwar, S.P. (2009b). Purification and Characterization of an Extracellular Laccase from a *Pseudomonas* sp. LBC1 and Its Application for the Removal of Bisphenol A. *J. Mol. Catalysis B: Enzymatic*, 61, 252 – 260.
106. Van-der Zee, F.P. and Cervantes, F.J. (2009). Impact and application of electron shuttles on the redox (bio) transformation of contaminants: a review. *Biotechnol Adv*, 27, 256 – 277.
107. Verma, Y. (2008). Acute toxicity assessment of textile dyes and textile and dye industrial effluents using Daphnia magna bioassay. *Toxicol. Ind. Health*, 24 (7), 491 - 500.
108. Wang, C.J., Hagemeier, C., Rahman, N., Lowe, E., Noble, M., Coughtrie, M., Sim, E. and Westwood, I. (2007). Molecular cloning, characterisation and ligand bound structure of an azoreductase from *Pseudomonas aeruginosa*. *J. Mol. Biol*., 373 (5), 1213 – 1228.
109. Wang, H., Zheng, X.W., Su, J.Q., Tian, Y., Xiong, X.J. and Zheng, T.L. (2009). Biological Decolorization of the Reactive Dyes Reactive Black 5 by a Novel Isolated Bacterial Strain *Enterobacter* sp. EC3. *J. Hazard. Mater.*, 171 (1-3), 654 – 659.
110. Wang, Y., Jiang, L., Shang, H., Li, Q. and Zhou, W. (2020). Treatment of Azo Dye Wastewater by the Self-Flocculating Marine Bacterium *Aliiglaciecola lipolytica*. *Environ. Technol. Innov*., 19, 100810.
111. Wijetunga, S., Li, X. and Jian, C. (2010). Effect of organic load on decolourization of textile wastewater containing acid dyes in up flow anaerobic sludge blanket reactor. *J. Hazard. Mater.*, 177 (1-3), 792 – 798.
112. Xu, M., Guo, J. and Sun, G. (2007). Biodegradation of Textile Azo Dye by *Shewanella decolorationis* S12 under Microaerophilic Conditions. *Appl. Microbiol. Biotechnol.*, 76 (3), 719 – 726.

113. Yemashova, N., Telegina. A., Kotova. I., Netrusova. A. and Kalyuzhnyi, S. (2004). Decolorization and partial degradation of selected azo dyes by methanogenic sludge. *Appl. Biochem. Biotechnol*., 119, 31 – 40.
114. Yoo, E.S., Libra, J. and Adrian, L. (2001). Mechanism of decolorization of azo dyes in an anaerobic mixed culture. *J. Environ. Eng.* (ASCE), 127, 844 – 849.
115. Yoo, E.S., Libra, J. and Wiesmannn, U. (2000). Reduction of azo dyes by *Desulfovibrio desulfuricans*. *Water Sci. Technol*., 41, 15 – 22.
116. Zhang, J., Feng, M., Jiang, Y., Hu, M., Li. S. and Zhai, Q. (2012). Efficient decolorization/ degradation of aqueous azo dyes using buffered H2O2 oxidation catalyzed by a dosage below ppm level of chloroperoxidase. *Chem. Eng. J.*, 191, 236 - 242.
117. Zollinger, H. (1991). Colour Chemistry: Synthesis, Properties and Applications of Organic Dyes and Pigments, 5th Edition, VCH Publishers, Weinheim, Germany, 187.