

Review Article

Microbial degradation of textile industry effluents: A review

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Citation

Aneela Sharif, Zahida Nasreen, Rabia Bashir and Sehrish Kalsoom. Microbial degradation of textile industry effluents: A review. Pure and Applied Biology. Vol. 9, Issue 4, pp2361-2382.

<http://dx.doi.org/10.19045/bspab.2020.90251>

Received: 09/03/2020

Revised: 16/06/2020

Accepted: 24/06/2020

Online First: 18/07/2020

Abstract

During textile processing, different waste materials are produced at different stages including dyes and wastewater. These chemicals and wastewater are ultimately released into environment that negatively affects its biota because of detrimental changes brought into the surrounding by these unused and untreated materials. The major problems being imposed by textile industry include: excessive usage of water, control of its frequent discharge into environment and treatment of this effluent loaded waste water. Industries are struggling to find out some novel solutions for treatment of these wastes to diminish the environmental damage being caused by effluent discharge. In recent years, there is an increasing trend of using different kinds of microorganisms for degradation purpose of textile industries effluents. Because of low cost and long lasting effect of biological remediation of industrial wastes, there has been an increasing demand for new and novel biological solutions for industrial effluent management. In this context, this review summarize major textile dyes, different bioremediation ways by which textile dye effluents can be treated and microbes capable of degradation and decolorization that can be applied in order to develop cost effective methods for textile effluents treatment.

Keywords: Azo dyes; Decolorization; Microbial degradation; Textile effluents

Introduction

Textile industry is considered one of the largest industry when it comes to amount of chemicals being used and thus it is the major contributor of chemical pollution in our environment. Complex chemicals and water is extensively used in textile industry during textile processing and untreated and unused leftover substances are released as waste water. This wastewater is heavily loaded with complex chemical compounds thus making this wastewater high in pH, color and lethal compounds. The mixing of this untreated wastewater into fresh water resources like ponds, rivers, streams, canals etc. is

increasing water pollution ultimately affecting the aquatic biota [1, 2]. Textile industry effluents are a mixture of many polluting substances of complex chemical nature including organochlorine-based pesticides to heavy metals and these are mostly important parts of different types of dyes being used in the dyeing process of fabrics [3].

Effective treatment of fabric industry discharge has thus become a major ecological problem. Because it is very difficult to eradicate dyes from textile waste discharge, there must be some proper treatment processes for effluents to be released into the

environment without affecting environmental health [4, 5]. In a broader sense, frequent encounter with textile dye effluents is a potential health threat and this has been reported to be direct or in direct cause of various health problems which include suppression of immunity system, autoimmune diseases, various complications of respiration, blood circulation, damage to central nervous system and neurobehavioral disorders, allergic reactions, different type of cancerous diseases, vomiting, copious diarrhea, tissue damage, eye skin disorders, eye infections, lung related problems are names to few [6].

Now-a-days, growing trend toward the practice of using microorganisms for environmentally friendly treatment of textile effluents has gain importance. Some microbes are reported to have potential to break down or absorb a large number of textile dyes effluents [7, 8].

In fact, some microorganisms which belong to different taxonomic groups such as different strains of bacteria, white rot fungi and algae also have ability to break down and decolorize various complex colored compounds that otherwise are difficult to remove from environment [9].

It is well recognized fact that under certain conditions, different bacterial strains have high capability to mineralize, decolorize and degrade different dyes [10, 11]. Different bacterial strains with potentiality to disintegrate textile dyes have drawn the attention of scientific community and there has been a growing interest toward this [12]. Bacterial oxidoreductive enzymes which include laccase, azoreductases etc. actively participate in dye decolorization activity of bacteria especially in azo dye color removal [13, 14]. Bacterial azo dye degradation involves an electron donor and sequence of enzymatic steps aided by azoreductase that catalyze the cleavage of azo linkages [15, 16].

Therefore, it is possible to exploit the ability of bacterial azoreductase enzymes to catalyze the azo bond cleavage in azo dye compounds for development of effective, biodegradable methods for textile effluents management [17].

Different algal sp. (*Chlorella* sp. *Oscillatoria* sp. etc) have also been investigated to check the efficiency of their azoreductase enzymes for disintegration of textile based azo dyes. According to some studies, the algal azo reductases have been shown to produce aromatic amines by breaking down azo bond of azo dye compounds. In relation to this, there are some algae that can carry out the direct degradation of azo dyes instead of converting them into aromatic compounds first [18].

Another eco-friendly approach toward biodegradation of textile dyes is the application of lignin degrading fungi and their enzyme complexes. Ligninolytic fungi contain an enzymatic system composed of three principal fungal enzymes: laccase, lignin peroxidase (LiP) and manganese peroxidase (MnP) and this system of three enzymes have been found to impart degradative ability to ligninolytic fungi [19, 20]. Textile industry waste water containing different types of dyes can be treated efficiently before its discharge by white-rot fungi that can decolorize azo dyes [21].

Lignin-degrading system (LDS) of fungi has been reported for effective degradation of variety of industrial pollutants. The effectiveness of pollutant degradation depends upon two factors:

- 1) Nature of contaminant
- 2) And the fungal sp. carrying out degradation processes [22, 23].

The different microbial enzyme systems like lignin degradation system of white rot fungi are being explored extensively to study the characteristics of these enzymes and to check their suitability for the decomposition of colored compounds [24].

Enzymes can be considered as biochemical mean for effective wastewater treatment. Both intracellular and extracellular microbial enzymes can be utilized for treatment purposes.

Enzymes are very efficient biological catalysts. These have the ability to target a specific pollutant without any effect on other components present in the effluent. Nor like fungi, the yeast can decolorize the dyes and can survive even in hostile conditions [25, 26].

The biosorption or uptake of chemicals by microbial mass is also useful. Biomass from different microbes such as algae, yeast, filamentous fungi and bacteria are reported to eliminate dyes through biosorption process [27].

Textile industry effluents

Dyes, pigments and aromatic compounds are among some of most commonly used chemicals which have numerous textile industry applications such as in dying, tanning of leather and also for coloring of different stuff being used in textile industries [27]. Different chemical substances discharged from the textile industries become a constant environmental pollutant. Serious environmental problems arise due to untreated effluents being released from textile industry sometimes to such levels that can seriously threaten human health, aquatic biota, domesticated animals and livestock and leave negative impacts on entire surroundings [28]. Out of 0.7 million tons dyes being produced in textile industry around the globe annually, it is assessed that about 200,000 tons of these resistant compounds are lost every year as effluent because of faulty dying processes [29, 30]. Unluckily most of these remain in the environment because of their high consistency against physical, chemical and microbial degradation and thus are continues threat to environment or to flora and fauna [31].

Textile industry dyes

Due to coloring properties, different type of dyes and pigments are widely used in textile industry as well as in other industries such as paper, plastics, leathers, and cosmetics industry. Large amount of water is used in textile processing that is being released untreated into the environment [32]. Dye effluents are one of the main pollutants carried to the environment, mainly by textiles industries. Classification of dyes depends upon their applications and chemical nature. There are two main components of a dye, first a group of atoms that causes dye color is known as chromophores and second are electron withdrawing or donating constituents of chromophores, called auxochromes [33]. The most predominant examples of chromophores are azo ($-N=N-$), carbonyl ($-C=O$), methine ($-CH=$), nitro ($-NO_2$) and quinoid groups. The examples of main auxochromes are amine ($-NH_3$), carboxyl ($-COOH$), sulfonate ($-SO_3H$) and hydroxyl ($-OH$) groups. On the basis of their chemical properties, auxochromes can fit into the following dye classes ; reactive, direct, acid, basic, disperse, pigment, vat, anionic, Sulphur, solvent and disperse dyes [34]. Azo dyes dominate with the maximum diversity of colors and are usually considered as largest class of dyes owing to their coloring properties [35]. Azo, anthraquinone and phthalocyanine are three most commonly used dyes that have high toxicity and also carcinogenic properties [11]. Because these are easy to manufacture, azo dye occupy approximately 80% of yearly making of commercial dyes throughout the world. Azo dyes (Table 1), as named on the basis of one or more azo bond ($R_1-N=N-R_2$) present in them, account for approximately 60-70% of all textile dyestuffs used in current era [36]. Because of their poor absorbability to the fibers and because of their constant chemical nature, their removal is very difficult from waste water by the usual treatments [37].

Different types of dyes are being used in industries these days. Fabrics having nitrogen such as wool, polyamine and silk are dyed by acidic dyes which are considered as largest class of dyes [38]. Basically, there are three types of textile dyes (Table 2) that are

cationic, anionic and nonionic types. Anionic dyes commonly include acid, reactive and direct dyes. Only one type of cationic dye being utilized in textile industry is basic dyes. Nonionic dyes which do not undergo ionization in solution are disperse dyes [39].

Table 1. Some azo dyes are as follow

Dye	Type	Chemical nature	References
Direct blue	Direct dye	Diazodye	[40]
Chrysoidine	Basic dye	Monoazo, cationic	[40]
Procion navy blue HER	Reactive dye	Azodye	[40]
Suoranol Red	Acid dye	Diazo	[40]
Golden yellow HER	NA	Sulfonated diazo	[41]
Reactive red HE3B	NA	Sulfonated monoazo	[41]
Disperse brown 3RL	NA	Monoazo	[41]

Table 2. Characterization of different dye classes is as follow

Dye Class	Characters	Solubility	Substrate	Major Chemical constituent	Mechanism of Rection	References
Acid	Anionic	Soluble in water	Nylon, wool, silk, modified acrylic	azo, anthraquinones and triarylmethanes, iminoacetone, nitro, nitrous and quinoline,	Applied from neutral to acidic dye baths	[42]
Basic	Cationic,	Soluble in water	Modified nylon, polyester, modified acrylic	azo, anthraquinone, triarylmethane, methane, thiazine, oxazine, acridine and quinoline,	Applied from acidic dye baths	[42]
Direct	Anionic	Soluble in water	Cotton, rayon, leather, nylon	azo compounds, with thiazoles, phtalocyanines and oxazines	Applied from neutral or slightly alkaline baths	[42]
Reactive	Anionic	Soluble in water	Cotton, nylon, silk, wool	azo compounds, anthraquinones and phtalocyanines	Reactive site on dye reacts with functional group on fiber to bind dye covalently under influence of heat and pH(alkaline)	[42]

Disperse	Nonionic	Very low solubility in water	Polyester, poly-amide, acetate, plastic, acrylic	N/A	Fine aqueous dispersions often applied by high temperature pressure or lower temperature carrier methods	[42]
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One of the most extensively applied dyes colorants in fabric industry are azo dyes making up to 60±70% of all dyestuff, anthraquinone group being on second in this list. Biological management of azo dyes from effluents is highly effective and these dyes are soluble in solution. Highly degradation resistant dyes are the type of dyes known as reactive dyes that are present in effluents released from textile industry [7]. Now-a-days, practice of using green technologies mainly for the purpose of protecting environment and for reducing environmental pollution is gaining wide attention. Microbes are widely being used for treatment of industrial effluents which have certain advantages. Some microbes being used for degradation are described below:

Role of Bacteria in biodegradation

Several researchers have studied different bacterial species for bioremediation of dyes, metals, soils and waters that are contaminated by textile effluents. Dyes that contain

carcinogenic compounds, heavy metals, halogen containing compounds, bleaching agents containing chlorine, formaldehyde etc. are some of the main pollutants of textile wastewater [43, 44]. Bacteria able to decolorize dye (Table 3) in pure cultures have already been described [45]. The mixed microbial culture bears more benefits than the application of pure cultures in the disintegration of colorants being utilized in textile industry. Dyes molecules may be directly attacked by different bacterial species or some strains are even able to further degrade the break down products that are formed by another strain [46].

The aerobic degradation of azo dye by bacteria is not effective; however, a group of aerobic and anaerobic bacteria has been shown to degrade some azo dyes (Table 4). *Pseudomonas leuteola* and *Bacillus subtilis* are some of the bacteria being used for anaerobic degradation [51].

Table 3. Percentage efficiency of some bacterial species to decolorize azo dyes is given in the following table

Bacterial Specie	% Efficiency Of decolorization	Optimum PH Required	References
<i>Pseudomonas putida</i>	90%	7	[8]
<i>Bacillus cereus</i> ,	65%	7-9	[8]
<i>Bacillus subtilis</i>	54%	7	[8]
<i>Pseudomonas sp</i>	78%	7	[47]
<i>Bacillus mycoides</i>	76%	N/A	[47]
<i>Micrococcus sp.</i>	77%	N/A	[47]
<i>Chryseomonas luteola</i>	42%	N/A	[48]
<i>Pseudomonas</i>	42.5%	N/A	[48]

<i>aeruginosa</i>			
<i>Aeromonas hydrophila</i>	90%	7	[8]
<i>Pseudomonas sp.</i>	97%	N/A	[41]
<i>Staphylococcus aureus</i>	79%	N/A	[49]
<i>Bacillus sp</i>	83%	N/A	[49]
<i>Klebsiella ozaenae</i>	95.89%	7	[50]

Table 4. Some of bacterial strains degrading synthetic dyes are listed in the following table

Bacterial strain	Synthetic dye	References
<i>Bacillus subtilis</i>	Reactive azo dyes	[51]
<i>Aeromonas hydrophila</i>	Acid Orange 7, Reactive Blue 160,	[52]
<i>Escherichia coli</i>	Ethyl Red, Methyl Red	[53]
<i>Sphingomonas xenophaga</i>	Acid Orange 7, 10	[54]
<i>Rhizobium radiobacter</i>	Reactive Red 141	[54]
<i>Pseudomonas luteola</i>	Reactive azo dyes	[55]
<i>Corynebacterium Glutamicum</i>	Reactive Yellow 2	[56]
<i>Pseudomonas aeruginos</i>	Direct Orange 39	[57]
<i>Staphylococcus arlettae</i>	Reactive Yellow 107, Reactive Red 198 and Direct Blue 71	[57]
<i>Alcaligenes faecalis</i>	Reactive, azo dyes, disperse dyes and phthalocyanine dyes	[58]
<i>Enterobacter agglomerans</i>	Methyl Red	[59]
<i>Bacillus megaterium</i>	Acid Red	[60]

Microbial mechanism to degrade and decolorize azo dye

Biological management of textile industry dyes is an efficient and environmentally friendly process. The Microbial mechanism for degradation and decolorization of most problematic textile dyes that are azo dyes involves cleavage of azo bonds in azo compounds, thus causing color removal of azo compounds. Azo dyes first undergo reductive cleavage and then resulting breakdown products which are aromatic amines mainly are metabolized in the presence of oxygen. Mostly, dyes are mineralized into simple inorganic compounds that are harmless for living organism and do not threat their life [61].

Microbial electron transport chain contains reduced flavin nucleotides for which azo dye in an oxidizing agent and is itself reduced during oxidation of flavin nucleotides and this process is followed by the reduced flavin nucleotides undergoing reoxidation. This process usually requires an additional carbon source for decolorization and degradation to

proceed at a feasible speed [62]. Some aerobic microbes utilize azo dyes as their only source of carbon and nitrogen, in others strains reduction of azo group can only be catalyzed by oxygen-tolerant azo reductases. This carbon is changed to methane and carbon dioxide, causing release of electrons. These electrons then move down electron transport chain to azo dye, which is acting as electron acceptor. Then there is reaction between electrons and azo dye, leading to reduction of azo bonds, and thus decolorization occurs [63]. Several other microbes such as bacterial strains, fungi, actinomycetes and algae are extensively been investigated for their azo dye decolorization capability [63, 64].

Algal degradation and decolorization of textile dyes (Phycoremediation)

Phycoremediation may be defined as the use of macro algae or microalgae for the elimination or biodegradation of pollutants, including textile dyes and xenobiotics from wastewater with simultaneous biomass

propagation. There are large number of processes for treating polluted water, industrial effluents, dyes, different colorants, bleaching and tanning agents using microalgae aerobically as well as an anaerobically [65]. Although bacteria have pivotal importance in degradation of environmental pollutants, microalgae have been shown to have organic pollutants degradation ability (Table 5) besides providing oxygen for aerobic bacteria that can only degrade pollutants in the presence of oxygen. Indeed, there have been lots of studies proving that current environmental problems such as textile industry effluents treatments issues can be resolved by using microalgae for degradation of pollutants into eco-friendly compounds [66]. Mutagenic and carcinogenic azo dyes and their intermediates compounds are causing many health related issues and are responsible for mutagenic activities in surface water that are polluted largely by textile waste water. Their release into surface water also leads to major issues,

causing obstruction of light being unable to penetrate and also hinders oxygen access into water bodies [67, 68]. The algae are photoautotrophs and they require no carbon source. The utilization of algae for waste water treatment is an efficient and cheap cost process. The growth of photosynthetic algae is visible even in the textile industry effluents and therefore they are the possible candidate for waste water treatment [69]. Good color removal can be achieved by algal azo reductase enzymes that is capable of breaking down azo dyes. *Chlorella* and *Oscillatoria* species have been shown to produce aromatic amines through degradation of azo dyes ultimately leading to formation of simple organic compounds through further break down of these aromatic amines. Few other algal species were even able to utilize azo compounds (Table 6) as only carbon and nitrogen source. *Chlorella sp.* and *Oscillatoria sp.* have been shown to degrade and decolorize more than 30 azo dyes into less complex aromatic amines [80].

Table 5. Some of dyes and color agents removed by algae are as follow

Algae	Dye removed	% efficiency of removal	References
<i>Cosmarium sp.</i>	Malachite Green	92.4%	[70]
Green Algae	Mono-azo and diazo Dyes	68%	[71]
Algal biomass	Malachite Green	85%	[72]
Green Algae	Indigo	89.3	[73]
Green Algae	Direct Blue	79%	[73]
Green Algae	Remazol brilliant Orange	75.3%	[73]
Green Algae	Crystal violet	72.5%	[73]
<i>Kluyveromyces marxianus</i>	Remazol Black-B	98%	[74]
<i>Chlorella sp.</i>	Indigo	89.3%	[75]
<i>Chlorella sp.</i>	Direct blue	79%	[75]
<i>Chlorella sp.</i>	Remazol brilliant orange	75.3%	[75]
<i>Chlorella sp.</i>	Crystal violet	72.5%	[75]
<i>Spirogyra sp.</i>	Blue dye	78.29%	[76]
<i>Spirogyra sp.</i>	Red dye	64.21%	[76]
<i>Oscillatoria sp.</i>	Blue dye	76.48%	[76]
<i>Oscillatoria sp.</i>	Red dye	62.63%	[76]
<i>Phormidium</i>	Indigo dye	91%	[77]
<i>Synechococcus sp.</i>	Remazol Brilliant Blue R)	11.53%	[77]
<i>Lyngbya sp.</i>	Textile dye	73%	[78]
<i>Lyngbya lagerlerimi</i>	Methyl Red	35.61%	[79]

<i>Nostoc linckia</i>	Methyl Red	81.97%	[79]
<i>Oscillatoria rubescens</i>	Basic Cationic	85.80%	[79]
<i>Chlorella vulgaris</i>	Basic Fuchsin	91.20%	[79]
<i>Elkatohrix viridis</i>	G-red	90.75%	[79]

Table 6. Some of other algal species actively involved in degradation process are following

Algal sp.	References
<i>Chlorococcum sp.</i>	[81]
<i>Chroococcus sp.</i>	[81]
<i>Desmococcus sp.</i>	[81]
<i>Chlamydomonas sp.</i>	[81]
<i>Chlorella sp.</i>	[82]
<i>Synechocystis sp.</i>	[82]
<i>Phormidium sp.</i>	[82]
<i>Spirogyra rhizopus</i>	[83]

Role of fungi in degradation and decolorization of textile dyes (Mycoremediation)

The practical of usage of fungi for achieving bioremediation of polluted soils and textile effluents is termed as mycoremediation. Different problematic substances such as petroleum hydrocarbon compounds, polychlorinated biphenyls, heavy metals (by biosorption), phenolic derived compounds, degradation resistant pesticides etc. have been reported to be degraded through mycoremediation. These hazardous

compounds are used by fungi as the nutrient source in this process of mycoremediation and changed them into simpler forms also causing their decolorization (Table 7). Fungi can be classified on the bases of its degradation efficacy under following terms:

- Ligninolytic fungal degradation
- Fungal biosorption
- Mycorrhizal fungal degradation [84].

Bjerkandera adusta, *Trametes versicolor*, *Phanerochaete chrysosporium* have been approved for textile dyes treatment through their ligninolytic activities [85].

Table 7. Dyes decolorization efficiency (%) of different fungal species is listed as follow

Fungal spp.	Dye decolorized	Rates of Decolorization	References
<i>Aspergillus flavus</i> SA2	Acid Red 151(di-azo)	97.70%	[86]
<i>Alternaria spp.</i> SA4	Acid Red 151(di-azo)	98.47%	[86]
<i>Aspergillus tereus</i> SA3	Acid Red 151(di-azo)	55%	[86]
<i>Penicillium spp.</i> SA5	Acid Red 151(di-azo)	65%	[86]
<i>Aspergillus flavus</i> SA2	Orange II (mono-azo)	48%	[86]
<i>Aspergillus tereus</i> SA3	Orange II (mono-azo)	44.67%	[86]
<i>Alternaria spp.</i> SA4	Orange II (mono-azo)	58.66 %	[87]
<i>Penicillium spp.</i> SA5	Orange II (mono-azo)	55.68 %	[87]
<i>Pleurotus florida</i>	malachite green	90%	[87]
<i>Schizophyllum commune</i> IBL-06	Brilliant red 80	84.8%	[87]

Role of White-Rot Fungi (WRF) In Textile Effluents Treatment

WRF have been shown to possess extraordinary dye decolorizing ability (Table

8). These are proficient in mineralizing a wide-ranging pollutants, while bacteria are substrate specific. The main reason behind this degradative efficiency of white rot fungi

to break down substances such pollutants and aromatic compounds is their lignin degrading enzymes, such as lignin peroxidase (LiP), manganese peroxidase (MnP) and laccase that are not substrate-specific [88, 89]. Lignin peroxidase released by *Phanerochaete Chrysosporium* has been reported to efficiently break down azo dye into simpler compounds [90].

Lignin, a polymer present in woody plants is broken down by WRF. The wood-rotting *Phanerochaete chrysosporium* is a white-rot fungus that is capable to degrade variety of xenobiotic pollutants such as dioxins, polychlorinated biphenyls (PCBs) and other

chloro-organics. *Coriolus versicolor*, *Trametes versicolor*, *Pleurotus ostreatus* and *Coriopsis polysona* are some other reported WRF that show ability to remove color from dyes [101]. LiP and Mn-dependent peroxidase (MnP) or laccase enzymes are main agents of color removal by WRF [102, 103].

Different fungal species are also capable of reducing heavy metals from waste laden water some of which are listed in (Table 9). *Trametes versicolor* is an specie of interest because of its ability to decolorize different colored compounds released from textile and other industries [109, 110].

Table 8. Some of synthetic textile dyes decolorizing white rot fungi are following

WRF Strain	Dyes decolorized	References
<i>Bjerkandera adusta</i>	Reactive Orange96, Reactive Violet 5	[91]
<i>Lentinus tigrinus</i>	Orange II , Reactive Blue 38	[92]
<i>Phlebia brevispora</i>	Brilliant Green, Crystal Violet	[93]
<i>Piptoporus betulinus</i>	Acid Green 27, Acid Red 106, Brilliant Yellow, Chrysophenine	[94]
<i>Stereum rugosum</i>	Remazol Brilliant Blue , Poly R-478	[95]
<i>Funalia trogii</i>	Remazol Brillant Blue	[96]
<i>Pleurotus pulmonarius</i>	Amido Black	[97]
<i>Pleurotus ostreatus</i>	Phenol Red, Bromophenol Red	[98]
<i>Phanerochaete chrysosporium</i>	Amido black 10B	[99]
<i>Coriolus versicolor</i> KR-11W	Congo Red, Methylene blue	[100]
<i>Phanerochaete chrysosporium</i>	Methylene blue, Poly R-478, Congo Red	[100]
<i>Coriolus versicolor</i> KR-65W	Methylene blue, Poly R-478	[100]

Table 9. Some of other fungal species capable of removing heavy metals from textile waste water are listed in the given table

Fungal specie	Metals	Adsorption capacity (mg g ⁻¹)	References
<i>Aspergillus niger</i>	Cu	5	[104]
<i>Mucor rouxe</i>	Pb	17	[105]
<i>Mucor rouxe</i>	Zn	4.89	[105]
<i>Mucor rouxe</i>	Cd,	6.94	[105]
<i>Mucor rouxe</i>	Ni	5.24	[105]
<i>Rhizopus nigricans</i>	Cr	47	[106]
<i>Rhizopus nigricans</i>	Pb	47	[106]
<i>Streptovercillium cinnamoneum</i>	Zn	21.3	[107]
<i>Penicillium chrysogenum</i>	Pb	116	[108]

Fungal enzymes and biodegradation

Fungi are the good producer when it comes to enzyme production. Surface culture method is used to produce commercial fungal enzymes [111]. White rot fungi are very successful entities with extraordinary lignin degradation ability. Extracellular oxidoreductases enzymes such as laccases, peroxidases and oxidases are produced by WRF that perform biodegradation [112]. The main role of these enzymes is to degrade

lignin but because these enzymes are not substrate-specific these are also capable to break different aromatic persistent compounds (Table 10) involved in causing environment related issues [113]. WRF are better dye-decolorizers as compared to prokaryotes. *P. chrysosporium* is a principle decolorizer compared to other microbes, whose decolorizing capability is due to lignin peroxidase (LiP) and manganese peroxidases (MnP) [114].

Table 10. Some of enzymes from different fungi degrading effluents are enlisted below

Effluent	Fungal sp.	Enzyme	References
Azo dyes	<i>Pycnoporus sanguineis</i>	Laccase	[115]
Bleach plant effluents	<i>P.sanguineis</i>	Laccase	[116]
PCBs	<i>P.chrysosporium</i> , <i>Trametes versicolor</i>	lignin peroxidase (LiP), MnP	[117]
non phenolic aromatic compounds	<i>Penicillium chrysogenum</i>	LiP	[118] [119]
phenolic compounds	<i>P.chrysosporium</i>	manganese peroxidase (MnP)	[119]
2, 6-dimethoxyphenol (DMP)	<i>Bjerkandera adusta</i>	MnP	[119] [120]
Bromophenol Red, Bromocresol Purple	<i>Pleurotus ostreatus</i>	MnP, MiP	[120]
Solar golden yellow R	<i>Scyzophyllum commune</i>	MnP, Laccase	[87]

The survival of fungi depends upon their ability to adjust their metabolism according to changing level of carbon and nitrogen. Intracellular and extracellular enzymes are produced by fungi to achieve this metabolic activity and these further carry out non-specific degradation of different resistant effluents such as aromatic hydrocarbons, organic waste, dye compounds etc. Non-substrate specific nature of fungal enzyme systems is the main reason behind their ability to disintegrate colored and metallic effluents [121]. Similar enzymes because of their low specificity for substrate (lignin) have also been employed successfully in the degradation of dyes. Only a few reports have shown the capability of Brown-rot fungi to remove various dyes [80].

Enzymatic degradation of textile effluents

Enzymes have several beneficial characteristics related to degradation. When it comes to the amount and composition of effluents, the most polluting effluent released from industrial sector is textile wastewater [122, 123]. The disadvantages that we face while using microorganisms for degradation activities can be overcome easily by using enzymes as an alternate [124]. Enzymes have the capability to efficiently break down a target pollutant (Table 11) with no effect on the other constituents in the wastewater. Therefore, pollutants that are quite resistant toward disintegration can easily be degraded by enzymes. Hydrolases, dehalogenases, transferases and oxidoreductases are some of the most important enzyme classes actively involved in bioremediation processes. An example of enzyme active in removal of

pollutants is Laccase [125]. Extracellular enzymes of ligninolytic fungi, white rot fungi are important for disintegration of dyestuff and also lignin [126]. It is advantageous to use WRF for degradative purposes than bacteria. The non-substrate specific nature of extracellular enzymes such as LiP, MnP, laccase and Mn-independent versatile peroxidases (VP) give white rot fungi this extraordinary efficiency to break down resistant aromatic color compounds [127]. Microbial enzymes have many desirable properties such as they give maximum

possible yields, their genetic makeup can easily be manipulated, easy availability due to absence of seasonal fluctuations and high growth of microbes than enzymes produced by plants and animals. Microbial enzymes are also important in that they have high stability and are easy to produce. Several dyes have been reported to be decolorized by white rot fungi which shows that these entities are an important alternative for management of industrial dye containing effluents [128].

Table 11. Some of the dyes being decolorized by enzyme mediated processes are as follow

Substrate	Enzyme and their source	References
3-(4 dimethyl amino-1 phenylazo) Benzene sulfonic acid.	Laccase from <i>Trametes villosa</i>	[129]
Acid Orange 6, 7 & Methyl Red	Bacterial Oxidoreductases from sludge Methanogens	[130]
Tartrazine and Ponceau	Azo reductase from Green Algae	[130]
Reactive Yellow	Azo reductase from <i>Staphylococcus arlettae</i>	[131]
Reactive Blue38, Reactive Black 5, Reactive Orange 96	Manganese peroxidase from <i>Phanerocheate chrysosporium</i>	[132]
reactive blue 19	Lacasse from <i>Trametes Versicolor</i>	[132]
Reactive Blue 59	Lignin Peroxidase from <i>Streptomyces krainskii</i>	[133]
Remazol Brilliant Blue R	Peroxidase and Laccase from <i>Pleurotus ostreatus</i>	[134]
Azo dye	Lignin peroxidase from <i>Penicillium ochrochloron</i>	[135]
Azo dye	Lignin peroxidase, tyrosinase, azoreductase and riboflavin reductase from <i>Bacillus sp.</i>	[135]

It was reported in another study that WRF breaks down Crystal Violet dye via *N*-demethylation. The main reaction of azo dyes disintegration by bacteria includes breakage of azo bonds by an azoreductase enzyme and an electron donor. Azo dyes containing textile waste water can be bio-treated effectively by developing treatment processes that use azoreductase producing microbes. These azoreductase enzymes can

catalyze the cleavage of azo compounds by reduction [136].

The most important bacterial enzymes involved in degradation activities are azoreductases (Table 12). Azoreductases cause breakage of azo bonds ($-N=N-$), producing aromatic amines which are further converted into CO₂ and H₂O under aerobic environments [137].

Yeast degradation ability

The large absorption of dyes, heavy metals, colorants makes the yeast a good microbe for bioremediation of azo dyes (Table 13). The enzymatic degradation and adsorption or the combination of both are the main practices by which yeast degrades azo dyes. The Remazol Blue and Reactive Red dyes can be efficiently removed up to 94 % and 44 % respectively by using *Candida tropicalis* [144]. There are only quite few studies about yeast decolorization ability. *Pseudozyma rugulosa* and *Candida krusei* are the yeast strains that exhibited excellent color removal

of reactive azo dyes. *Saccharomyces cerevisiae* effectively decolorize methyl red at different pH with involvement of azoreductase [145].

There is growing interest for biological treatment of waste water compounds such as textile effluents mainly dyes, metals, inorganic nutrient, and organic compounds through biosorption, biodegradation, bioaccumulation, and enzymatic mineralization [151]. The fungi reduce azo dyes by producing extracellular enzymes such as peroxidases and phenol oxidases [152].

Table 12. Bacteria with azoreductase activity are described below

Sr. No.	Bacterial strain	References
1	<i>Pseudomonas luteola</i>	[138]
	<i>Pseudomonas aeruginosa</i>	[138]
3	<i>Klebsiella pneumoniae</i>	[139]
4	<i>Clostridium perfringens</i>	[139]
6	<i>Enterococcus</i> spp	[140]
7	<i>Streptococcus</i> spp	[141]
8	<i>Bacillus cereus</i>	[142]
9	<i>Streptomyces</i> spp	[143]

Table 13. Some of yeast (Ascomycetes) involved in remediation of different dyes are listed here

Yeast Sp.	Dyes	References
<i>Candida krusei</i>	Reactive azo dye	[145]
<i>Saccharomyces cerevisiae</i>	Malachite Green	[145]
<i>Candida zeylanoides</i>	Azo benzenesulfonates	[146]
<i>Candida tropicalis</i>	Reactive Blue 19,	[147]
<i>Candida kursei</i>	Basic Violet 3	[148]
<i>Kluyveromyces marxianus</i>	Remazol Black B	[148]
<i>Pseudozyma rugulosa</i>	Reactive azo dye	[149]
<i>Torulopsis candida</i>	Reactive Brilliant Red	[150]
<i>Trichosporon beigelii</i>	Crystal Violet, Methyl violet Malachite Green	[150]

Degradation of textile effluent through biosorption

The absorption or uptake of chemicals by microbial mass is known as biosorption or more precisely it can also be described as “the capability of microbes to amass heavy metals from wastewater through metabolic or physio-chemical paths of absorption” [153]. It mainly occurs through cell wall, whereas adsorption

and absorption depending upon biomass type [154].

Algae, yeast, filamentous fungi and bacteria can be used to eliminate dyes from wastewater by biosorption by using their biomass. Heteropolysaccharide and lipid are integral part of the cell wall and have different functional groups such as amino, carboxyl, hydroxyl group and other charged components and have

biosorption properties. Strong attractive forces develop between the azo dye and these functional groups of cell wall of different microbes such as yeast, algae bacteria and filamentous fungi. Thus these components of cell wall are responsible for biosorption capacity of microbes [155].

Biosorption is attribute of specific type of microbial biomass to make bond with and to accumulate wastes and heavy metals present in effluents. Biomass has ability to act just like a chemical element or ion exchanger that is originated from biological source. The main component of fungi, bacteria and algae responsible for biosorption is cell wall. Until now, it has been widely reported that biosorption is a perfect substitute for cleansing of metal holding effluents [156].

Biosorption with microorganisms, especially fungus (Table 9) for elimination of colorants from textile waste water has gained significant attention. Decoloring of synthetic dyes and dye effluents have been studied by using different fungi. With respect to bacterial biosorption capacity, *Aeromonas sp.*, *Pseudomonas luteola*, *E. coli*, *Bacillus subtilis* and *Staphylococcus aureus* are some of bacterial strains being used for their bio sorbent properties for decontamination of class of dyes known as reactive dyes. The chief advantages offered by biosorption over old treatment processes include high effectiveness, low cost, minimization of sludge, recovery of metals, bio-sorbent regeneration, easiness to recover metals etc. [157].

Mechanisms of biosorption

There are many ways by which microbes can take up metals and this is due to their complex structure. There are many criteria to classify biosorption processes. Biosorption processes

based on cellular metabolism can be classified as follow:

1. Metabolism dependent biosorption
2. Non -metabolism dependent biosorption

Biosorption can also be classified as intracellular/extracellular biosorption and cell surface sorption depending upon the location where metal biosorbed from effluents is found [158].

A typical biosorption route has two phases;

1. A solid phase (sorbent or biosorbent; commonly a living material)
2. And a liquid phase (solvent, usually H₂O) comprising a dissolved substance to be sorbed (sorbate, a metal ion) [153].

Biosorption and heavy metal removal

Biosorption refers to the elimination of heavy metals and other harmful substances from a liquid solution by passively binding to non-living biomass. From this, it can be concluded that process is not metabolism dependent. Bioaccumulation, in contrast refer to an active removal of various metals by living organisms and this process is controlled metabolically. Different bio-sorbents organisms include algae, bacterial strains, different yeasts strains, fungi (Table 14) can be used to treat heavy metal effluents [159, 160].

There are two chief mechanisms by which metals are biosorbed [161, 162].

1. Active biosorption (metabolism-dependent)
2. And passive (metabolism- independent).

Active process of biosorption requires specific kind of conditions such as pH, temperature, nutrients that are necessary for maintain cellular functions. Passive biosorption processes, in contrast, occurs in living as well as in dead cells and take place under wide-ranging environmental conditions. The passive processes are more efficient as compared to active biosorption [162, 163].

Table 14. Some microbial species used in metal biosorption are follow

Microbial spp.	Metal absorbed	References
<i>Saccharomyces cerevisiae</i> ,	Cd	[164]
<i>Kluyveromyces fragilis</i>	Cd	[164]
<i>Arthrobacter sp.</i>	Pb	[165]
<i>Penicillium chrysogenum</i>	Pb	[165]
<i>p. digitatum</i>	Pb	[166]

Conclusion

Microorganisms are organisms of interest because of their efficiency for degradation. These include bacteria that are useful especially for degradation of resistant azo dyes which are being used extensively in textile industry. Algae are also being used widely for degradation and decolorization of textile effluents. Several algal species have capability of degrading different dyes, colorants and also organic pollutants. Similarly, fungi also have huge importance in bioremediation process. Different fungal enzymes have potential to breakdown different dyes with greater efficiency. Most important fungal species in context of degradation is white rot fungi which can degrade complex effluents by using different enzymes. Enzymes can provide an alternate for effluent treatment because of their absorption and degradation properties. Enzymes, the biological catalysts can take up different dyes including most resistant azo dyes. The enormous absorption of dyes and heavy metals makes the yeast a good candidate for biodegradation of azo dyes. Thus it can be concluded that microorganisms have huge potential for remediation of effluents and can successfully be employed for making our environment clean and healthy. So, there is a need for further exploration of degradation capabilities of different microbes.

Authors' contributions

Analyzed the data: A Sharif & Z Nasreen, Contributed materials/ analysis/ tools: R Parveen & S Kalsoom, Wrote the paper: A Sharif.

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