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A critical review on the treatment of dye-containing wastewater: Ecotoxicological and health concerns of textile dyes and possible remediation approaches for environmental safety

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A R T I C L E I N F O

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A B S T R A C T

The synthetic dyes used in the textile industry pollute a large amount of water. Textile dyes do not bind tightly to the fabric and are discharged as effluent into the aquatic environment. As a result, the continuous discharge of wastewater from a large number of textile industries without prior treatment has significant negative consequences on the environment and human health. Textile dyes contaminate aquatic habitats and have the potential to be toxic to aquatic organisms, which may enter the food chain. This review will discuss the effects of textile dyes on water bodies, aquatic flora, and human health. Textile dyes degrade the esthetic quality of bodies of water by increasing biochemical and chemical oxygen demand, impairing photosynthesis, inhibiting plant growth, entering the food chain, providing recalcitrance and bioaccumulation, and potentially promoting toxicity, mutagenicity, and carcinogenicity. Therefore, dye-containing wastewater should be effectively treated using eco-friendly technologies to avoid negative effects on the environment, human health, and natural water resources. This review compares the most recent technologies which are commonly used to remove dye from textile wastewater, with a focus on the advantages and drawbacks of these various approaches. This review is expected to spark great interest among the research community who wish to combat the widespread risk of toxic organic pollutants generated by the textile industries.

1. Introduction

Currently, water contamination because of the inability of textile industries to properly dispose of their waste water is one of the major challenges that affects the whole world. Textile industries are major contributors to the global economy and environmental pollution in many countries, including China and South African estuaries (Olisah et al., 2021). Wastewater containing dyes is a significant polluter of the environment which also affects human health, as textile industries generate large amounts of highly colored wastewater containing a diverse range of persistent pollutants (Almroth et al., 2021; Ali et al., 2022). Annually, about 7×10^7 tons of synthetic dyes are produced worldwide, with over 10,000 tons of such dyes used by textile industries (Chandanshive et al., 2020). Dyes are often divided into several categories according to their origin, structure, and application (Holkar et al., 2016; Akpomie and Conradie, 2020). Of these synthetic dyes, azo, direct, reactive, mordant, acid, basic, disperse, and sulfide dyes, are widely used by textile industries (Fig. 1). Natural and synthetic fibers used in the textile industry include wool, cotton, silk, polyester, polyamide, and acrylic (Deopura and Padaki, 2015; Silva et al., 2021). Furthermore, textile industries use a large number of highly toxic chemicals at various stages of the process, such as sizing, softening, desizing, brightening, and finishing agents (Kishor et al., 2021). However, textile dyes do not bind tightly to fabric and are discharged as

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effluent alongside wastewater into aquatic environments such as lakes, rivers, streams, and ponds without prior treatment, posing serious eco-toxicological threats with toxic effects on living organisms (Parmar et al., 2022).

Textile wastewater has been found to contain a wide range of toxic dyes, heavy metals, such as mercury, chromium, cadmium, lead, and arsenic which are required in the production of textile dye color pigments, as well as aromatic compounds. The presence of heavy metals such as mercury, chromium, cadmium, lead, and arsenic is required in the production of textile dye color pigments (Singha et al., 2021). These toxic chemicals are transported over long distances together with the wastewater. They then remain in the water and soil for long periods of time, posing serious health risks to living organisms and reducing soil fertility as well as the photosynthetic activity of aquatic plants, resulting in the development of anoxic conditions for aquatic fauna and flora (Dutta and Bhattacharjee, 2022). Textile dyes also degrade the esthetic quality of water bodies by increasing biochemical and chemical oxygen demand, thereby impairing photosynthesis, inhibiting plant growth, entering the food chain, providing recalcitrance and bioaccumulation, and potentially promoting toxicity, mutagenicity, and carcinogenicity (Mudhoo et al., 2020; Patil et al., 2022). The large amounts of water used in fabric manufacturing result in equally large amounts of wastewater containing high levels of dissolved solids, organics, metals, salts, and recalcitrant dyes (Ismail and Sakai, 2021), because of the high durability and solubility of synthetic dyes in water, conventional treatment options are frequently ineffective (Shindhal et al., 2021), while secondary pollution and inefficient removal of organic load upon discoloration necessitate the use of advanced approaches (Samsami et al., 2020). Therefore, there is an urgent need to develop cost-effective and environmentally friendly treatment approaches for adequately treating dye-containing wastewater prior to its final disposal into the environment. Under this premise, this review will provide a detailed knowledge on the adverse impacts of dye-containing textile wastewater on natural ecosystems and living organisms along with the various existing and advanced treatment approaches for the better management of textile wastewater with a view to working towards environmental safety.

2. Toxicity and the impact of textile dyes

The untreated effluents released by the textile industry contain a diverse range of organic pollutants, the most prevalent of which are textile dyes (Oyeniran et al., 2021). Azo dyes, which contain one or more azo groups structurally, are the largest class (above 60%) among the various groups of textile dyes and the most widely used dyes in the textile industry (Ayed et al., 2011; Bhattacharya et al., 2018; Thangaraj et al., 2021). Inefficient textile dyeing processes cause 15–50% of azo dyes that are not bound to fibers and fabrics to be released into generated wastewater (Chung, 1983; Singha et al., 2021). Some textile factories treat their wastewater to degrade the free azo dyes released into the environment, while others discharge untreated industrial effluents directly into bodies of water, posing serious ecotoxicological threats as well as toxic effects on living organisms (Fig. 2). Farmers in developing countries used to irrigate their agricultural lands with wastewater containing untreated industrial effluents, which had a negative impact on soil quality and crop germination rates (Jiku et al., 2021; Ao and Zayed, 2022).

Azo dyes discharged into water reduce light penetration, impairing the performance of algae and growing aquatic plants. Furthermore, dyes ingested by fish and other living organisms can be metabolized in their bodies into toxic intermediates, which can have a negative impact on the health of both the fish and their predators (Elgarahy et al., 2021).

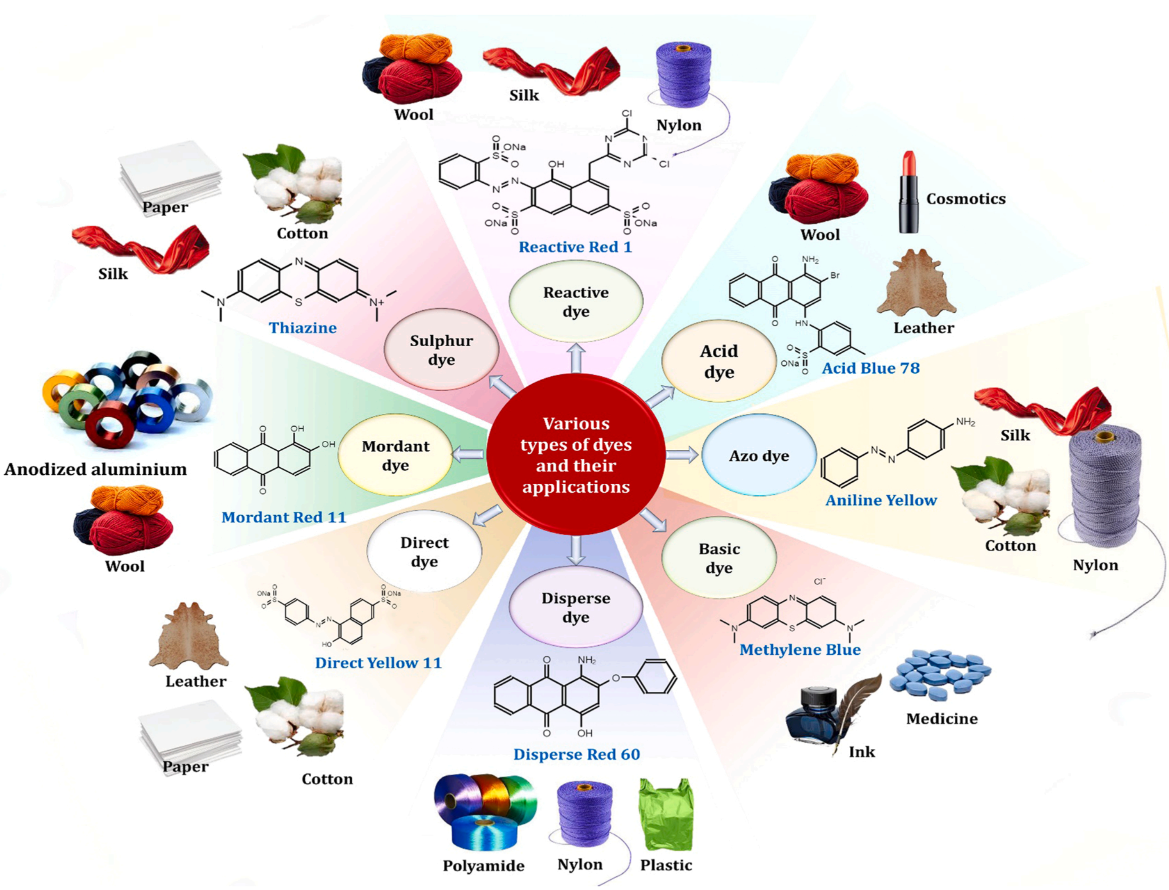

Fig. 1. Various categories of dyes and their possible industrial applications.

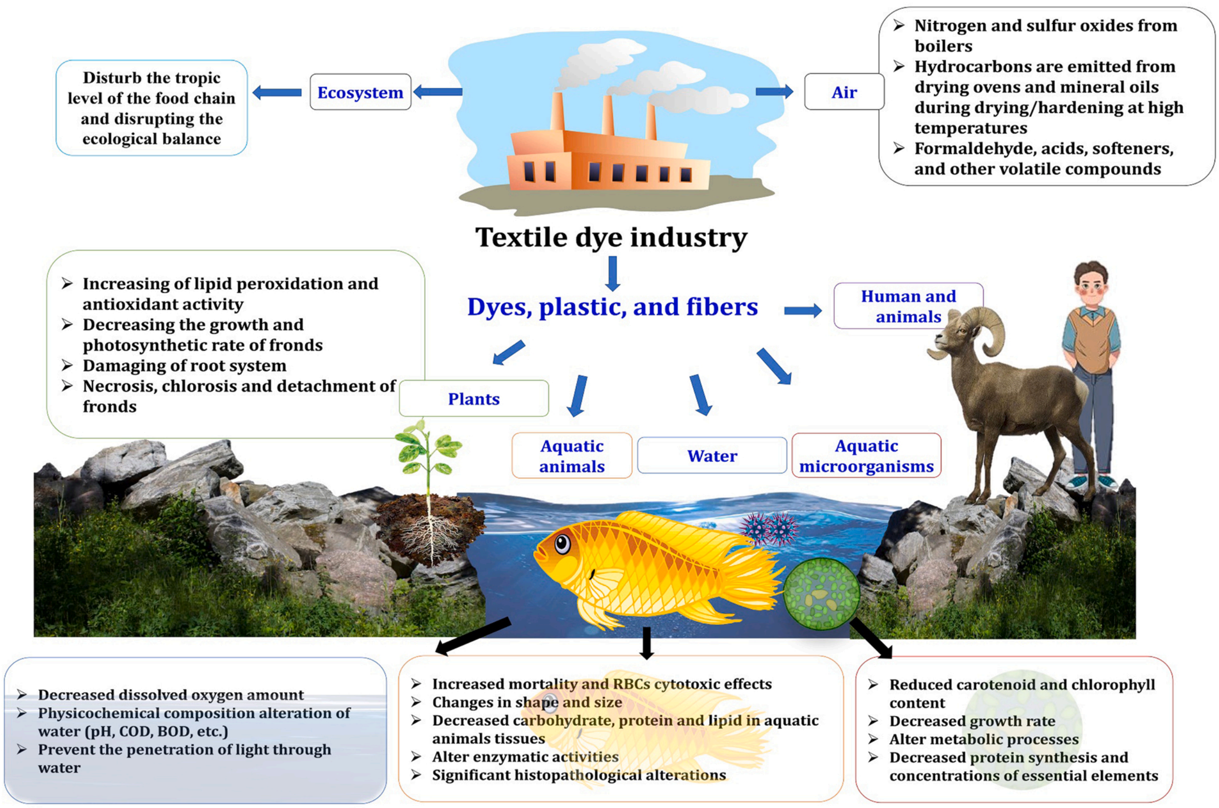

Fig. 2. Ecotoxicological impacts of dye-containing textile wastewater on the environment and living microorganisms.

Humans and other mammals can be exposed to azo dyes in industrial effluents through oral ingestion or direct skin contact (Manickam and Vijay, 2021). Intestinal microflora in the human gut converts azo dyes into toxic amino acids, which have a negative impact on various tissues in the human body (Feng et al., 2012). Furthermore, bacteria cultured from human skin were able to degrade azo dyes and produce carcinogenic amines (Kishor et al., 2021). Owing to the large number of textile industries and the vast amounts of wastewater containing dyes, appropriate and effective management techniques are necessary in order to prevent the contamination of ecosystems and to increase sustainability. However, the presence of other inorganic and organic constituents, their toxicity, as well as the relevant environmental discharge levels, must be taken into consideration in choosing the most suitable treatment technology (Lellis et al., 2019; Li et al., 2022).

2.1. Impact of textile dyes on aquatic and terrestrial environments

Despite the fact that water covers more than 71% of the earth's surface, one of the most important issues confronting humanity today is a lack of pure, high-quality drinking water. The demand for pure drinking water is increasing at an alarming rate, with estimates indicating that agriculture, industry, and households use 70%, 19%, and 11% of available water, respectively (Gupta et al., 2015; Chen et al., 2021a, 2021b). The textile industry contributes significantly to the deterioration of water quality, which will contaminate nature indefinitely and humans have interacted with natural habitats negatively (Fig. 2) by depositing contaminants deposition in terrestrial habitats and aquatic ecosystems (Soni et al., 2021).

Massive amounts of treated or untreated effluent containing azo dyes and other organic pollutants are disposed of by the textile industry. However, because azo dyes degrade prior to or after disposal, treated effluents contain amino acids that are likely more toxic than their raw substances, whereas untreated wastewater has a wide range of negative impacts on aquatic environments and living organisms (Khalaj et al., 2018; Mudhoo et al., 2020). Textile dyes that are discharged into aquatic ecosystems have a negative impact on aquatic flora (Fig. 2). The more visible natural issue with dye is the absorption and reflection of sunlight into water. It prevents light from entering the photic zone of the aquatic environment (Liang et al., 2017). As a result, there are significant ecological consequences, such as changes in the nature of aquatic ecosystems and decreased photosynthesis when compared to aquatic vegetation (Khan et al., 2015). Furthermore, because these waste liquids can cause allergies, dermatitis, skin irritations, malignancies, and mutations in humans, they can cause a variety of serious problems, including deterioration of water quality (odor and color) thereby rendering it toxic (Sarvajith et al., 2018). While a high concentration of textile dyes in water depletes oxygen levels, blocks sunlight, and impairs the biological activity of aquatic flora and fauna (Ghaedi et al., 2015). Furthermore, due to their resistance to conventional physicochemical degradation and lack of biodegradability, 60–70% of azo dyes are poisonous, carcinogenic, and resistant to standard treatment techniques (Rawat et al., 2018). This interfered with photosynthesis in marine plants by causing eutrophication as a result of the uncontrolled release of mineral elements resulting in long-term hazards.

Fish and other aquatic organisms which are a major source of protein, can cause symptoms such as cramps, fever and hypertension if they are consumed by humans whilst retaining dyes (Amer et al., 2022; Sharma et al., 2022). The presence of dyes and textile pigments in wastewater, on the other hand, causes it to be highly colored, with a variable pH and high levels of biological oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC), and suspended solids. These suspended solids obstruct the flow of water through the fish's gills, preventing gas exchange and potentially resulting in a decreased growth rate or death (Berradi et al., 2019). Furthermore, chronic exposure to textile effluents reduced fish feed consumption, resulting in a lower protein, carbohydrate and lipid content as well as a lower growth rate (Almroth et al., 2021). The reactive azo dyes can induce genotoxic effects in adult fish by increasing the rate of erythrocytic micronuclei formation in a dose- and time-dependent manner, while in fingerlings they increased the generation of gill micronuclei in a time-dependent manner (Zheng et al., 2021; Sharma et al., 2022). Due to the hypoxic negative effects on their immune system and physiological responses, fish are susceptible to various diseases (Fig. 3). As a result, contaminated fish have a significant impact on human health (Zheng et al., 2021).

Natural regulating processes can no longer compensate for bacterial oxygen consumption when organic matter, including dyes and pigments, is discharged into receiving media *via* textile finishing effluents (Wan et al., 2017). This can lead to under-oxygenation in stagnant aquatic environments, where bacteria decompose 7–8 mg of organic matter, which is enough to deplete the amount of oxygen in one liter of water (Lim et al., 2010). Organic matter agglomeration in watercourses results in an unpleasant taste, bacterial multiplication, pestilential odors, and erroneous coloration (Khattab et al., 2018). Color was detected with the naked eye from a dye mass concentration of 5 g/L (Lim et al., 2010). Apart from their unsightly appearance, coloring chemicals can interfere with light transmission in water, preventing aquatic plants from successful photosynthesis (Cardoso et al., 2012). Synthetic organic dyes are chemicals that cannot be purified using standard biological degradation processes (Allaoui et al., 2016). Unsaturated molecules are less persistent than saturated compounds because their chemical reactivity is strongly related to their persistence. The number of substituents increases the durability of aromatic compounds, whereas the presence of halogen substituents increases the persistence of dyes with alkyl groups (Lim et al., 2010).

Microalgae play an important role in aquatic ecosystems as primary producers which are both an economically and ecologically beneficial species. However, dye contamination inhibits microalgal growth and disrupts trophic transmission of energy and nutrients in aquatic ecosystems (Fig. 2). The large amount of textile dyes released into rivers, lakes, oceans, and seas has an effect on several parameters of algal growth, including pigment, protein, and other nutrients. Because algae are more susceptible to contaminants than other aquatic species, they are an excellent indicator of pollution in toxicological investigations (Sharma et al., 2021). Methylene Blue is a widely used cationic dye in a variety of textile industries, and it produces potentially carcinogenic aromatic amines such as benzidine and methylene. As a result, the toxicity of Methylene Blue was investigated on the microalgae *Spirulina platensis* and *Chlorella vulgaris*, which were selected based on their nutritional, economic, and ecological values (Ali and Saleh, 2012). *S. platensis* and *C. vulgaris* were exposed to varying doses of Methylene Blue dye, which resulted in a concentration-dependent decrease in specific growth rate, protein, and pigment content. As well, Methylene Blue inhibits the synthesis of chlorophyll after dye exposure and consequently reduces their development and photosynthetic rate (Ali and Saleh, 2012).

Aquatic macrophytes are being used to assess the phytotoxicity of textile dyes as a natural ecological marker. Numerous metrics are used to determine a plant's vigorous growth, including its dry weight, number of fronds, total frond area, and chlorophyll content (Colin et al., 2016; Singh et al., 2021). All of the macrophyte's parameters are changing as a result of the toxicity of textile dyes (Fig. 2). Numerous studies have established that dye has a significant effect on the rate of development and inhibits the growth of aquatic macrophytes (Lobiuc et al., 2018; Hocini et al., 2019; Adomas et al., 2020; Rápó et al., 2020; Singh et al., 2021). This is due to oxidative stress or a change in the photosystem of the plant as a result of decreased electron transport in the chloroplasts (Sree et al., 2015). *Lemna minor* is a critical component of the food chain. Therefore, a study was conducted to determine the effect of Congo Red and Gentian Violet dyes on the biosynthesis of biogenic amines by *L. minor* (Adomas et al., 2020). Clearly, these dyes inhibited *L. minor* growth, biomass production, and chlorophyll biosynthesis. In addition, Gentian Violet was more lethal than Congo Red because it disrupted the biosynthetic pathway for biogenic amines. The results indicate that decarboxylase activity and biogenic amine concentrations are sensitive and early indicators of these textile dyes' phytotoxic effects on *L. minor* (Adomas et al., 2020).

Textile dyes and/or their effluents alter soil chemistry and disrupt

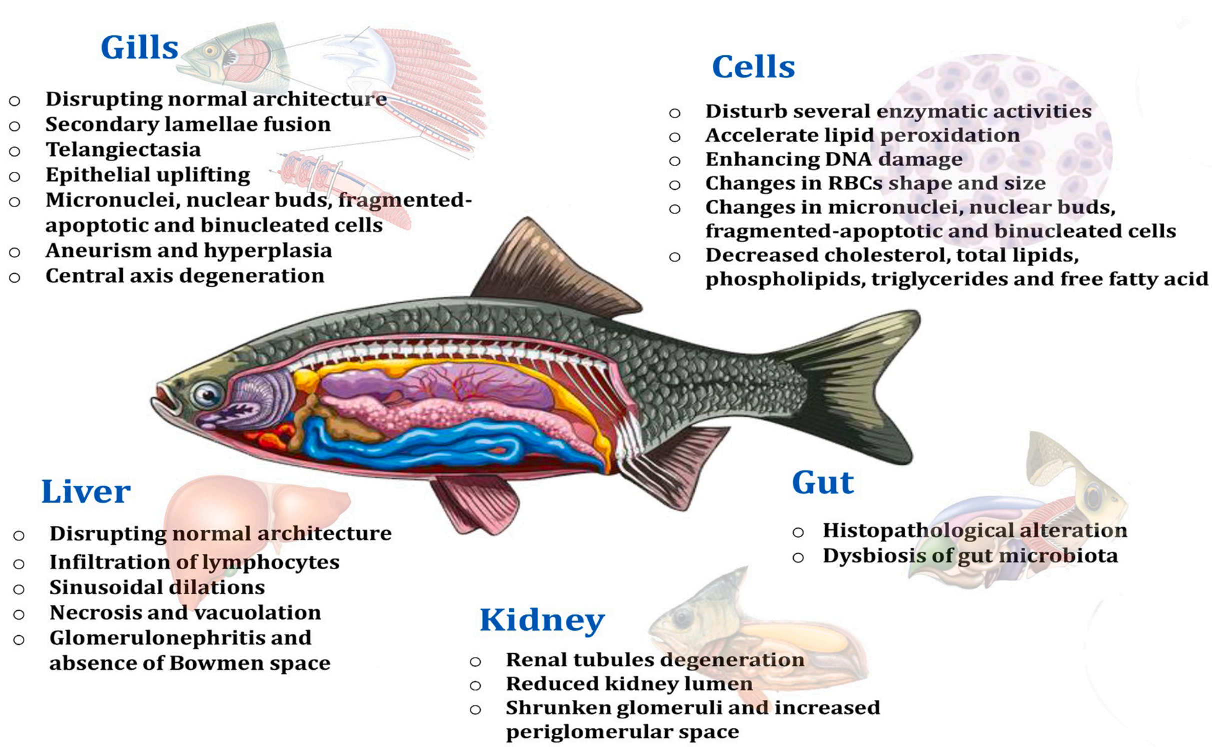

Fig. 3. Impact of toxic dye-containing wastewater on aquatic flora such as fish and related various diseases.

the balance of soil microbial flora. These organic pollutants also have a negative impact on plant flowering and germination (Fig. 2). The percentage of seed germination, as well as seedling height and survival, are considered to be the primary indicators of a plant's growth and health following exposure to textile dyes (Arshad et al., 2020). Additionally, growing plants synthesize dry matter as evidenced by their healthy and green shoots, which indicate a high chlorophyll content and an active photosynthesis process. Thus, the higher the concentration of solids containing dyes in industrial effluents, the more detrimental effects on plant growth occur (Zou et al., 2019). Increased solids concentration in polluted wastewater also depletes the dissolved oxygen required by seedlings and disrupts the seeds' osmotic balance (Hassan and Carr, 2018). Furthermore, increased dissolved solids concentrations deplete the chlorophyll content of plants. As a result, decreased chlorophyll levels have an effect on the photosynthetic process, slow plant growth, and reduce the accumulation of plant dry matter (Sharma et al., 2020) as given in Fig. 2. It has been reported that abscisic acid in high concentrations degrades chlorophyll and inhibits plant growth by impairing the synthesis of new chlorophyll (Zhu et al., 2017). Additionally, textile dye effluents can cause an increase in proline accumulation in plants, indicating that the dyes are causing stress (Ebency et al., 2013). Micronucleus and chromosomal aberrations are among the genotoxic effects of industrial effluents containing azo dyes on the seeds of *Allium cepa*. After exposure to low concentrations of the Black Dye Commercial Product, meristematic cells of *A. cepa* develop chromosomal aberrations, micronuclei, and cell death (Ventura-Camargo et al., 2011).

2.2. Impact of textile dyes on human health

Textile dyes, which are highly toxic and potentially carcinogenic, have been linked to a variety of human and animal diseases (Tounsadi et al., 2020; Jin et al., 2021). Textile dyes can cause diseases from dermatitis to problems with the central nervous system (Fig. 4). These problems may be caused by the substitution of enzyme cofactors, which results in the inactivation of the enzymes themselves (Wu et al., 2021). Ingestion or inhalation of textile dyes can cause skin and eye irritation, especially if they are exposed to dust (Clark, 2011). Workers who handle reactive dyes are at risk of developing allergic reactions such as contact dermatitis, allergic conjunctivitis, rhinitis, and occupational asthma (Hanger, 2003). As depicted in Fig. 5, Immunoglobulin E (IgE) antibodies that bind to histamine are produced when a conjugate of human serum albumin and the reactive dye is formed, acting as an antigen.

The textile industry is exposed to potentially toxic substances, some of which may interfere with ovulation and spermatogenesis (Suryavathi et al., 2005). Because of their widespread use in the textile, paper, and leather industries, azo dyes derived from benzidine and its derivatives have been thoroughly investigated for their toxicity, which has been linked to human bladder cancer (Tounsadi et al., 2020). In mammals, intestinal microflora metabolize azo dyes to their parent amines, which are easily absorbed by the gut, and their presence in human and animal urine has been documented (Amin et al., 2016). Textile dyes such as Reactive Green 19, Disperse Red 1, and Reactive Blue 2 all have a long-term genotoxic effect on human health. Reactive Green 19 was found to be genotoxic in a dose-dependent manner, whereas Reactive Blue 2 and Disperse Red 1 were not (Leme et al., 2015).

Due to the widespread use of dyes, they can be detected in the environment and accumulate physiologically along the food chain in freshwater flora such as fish and algae (Fig. 2) as reported by Hossain et al. (2018). It has been reported that toxic levels of organic compounds in humans are 1000 times higher than their initial concentrations in

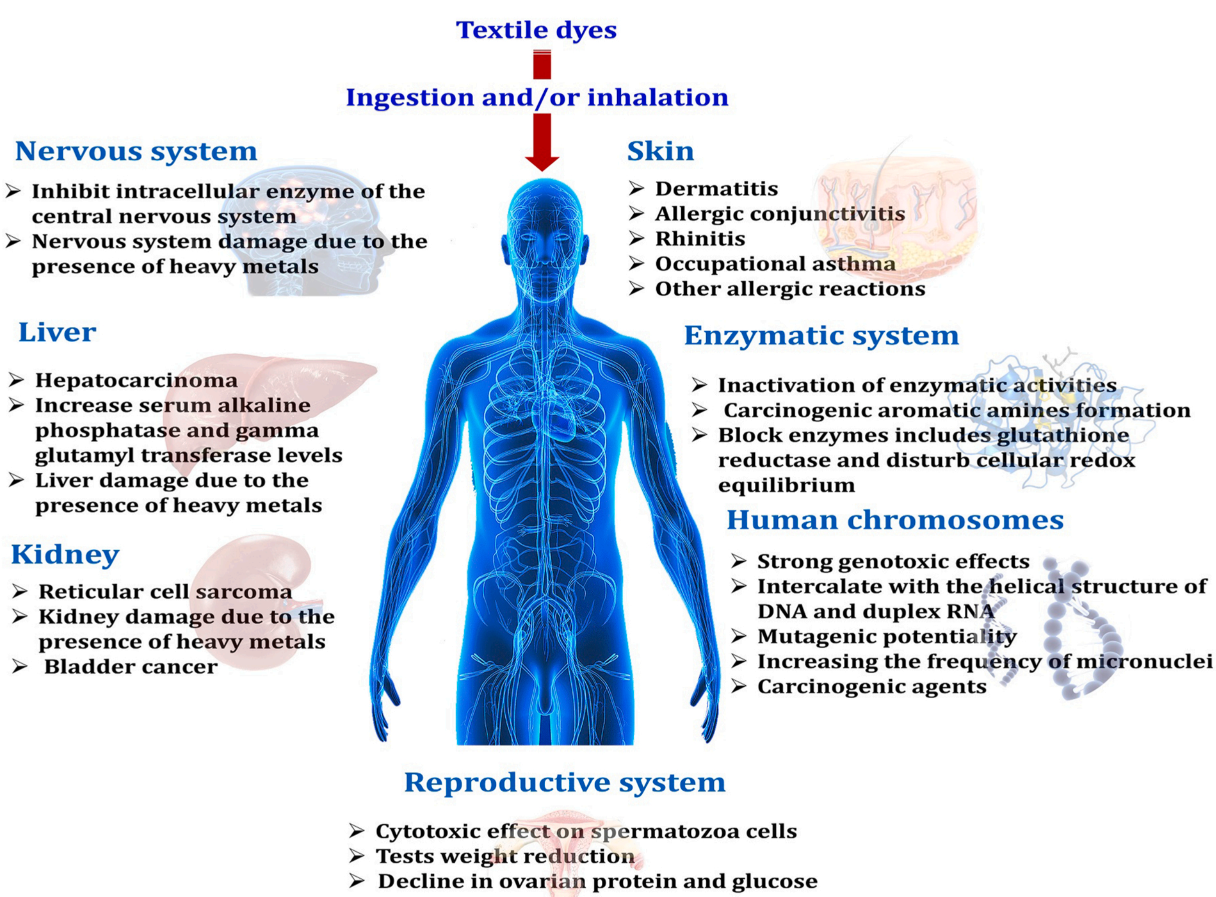

Fig. 4. Negative impacts of textile dyes on human health from dermatitis to central nervous system.

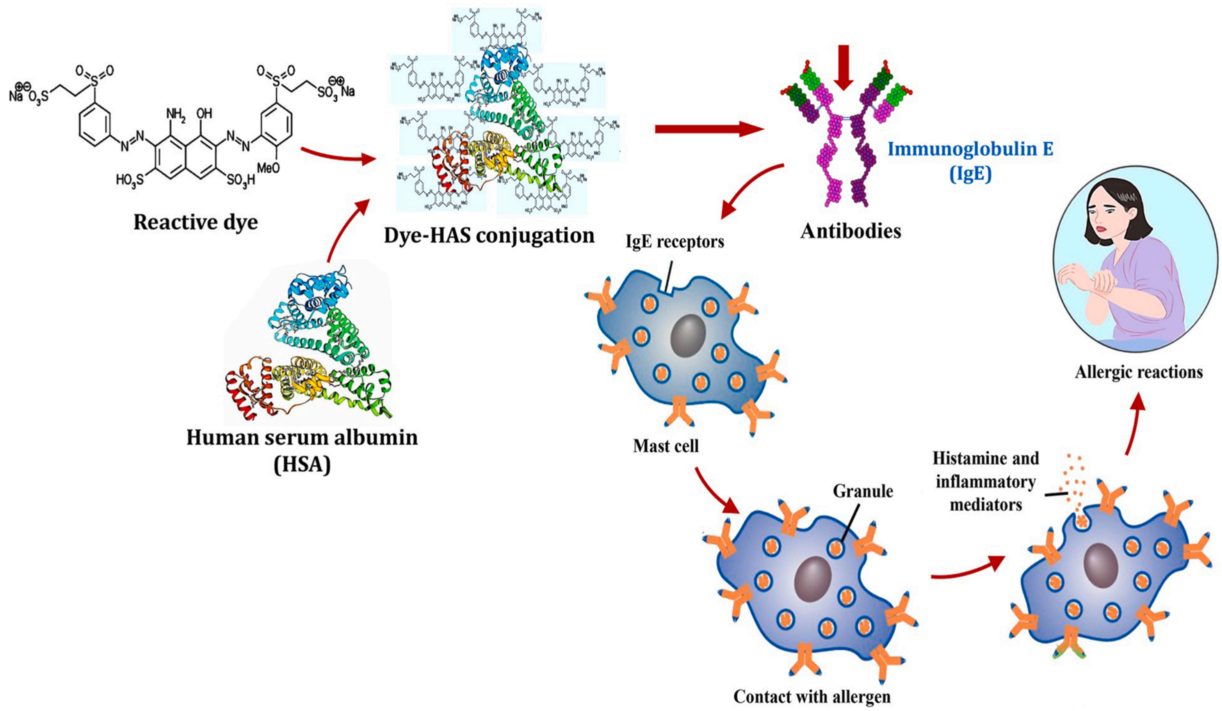

Fig. 5. The proposed mechanism of allergic reactions as a consequence of human serum albumin conjugation with textile dyes such as reactive dyes, resulting in histamine and inflammatory mediators production.
Adopted from Hanger (2003).

water (Korpi et al., 2009). During water treatment, chlorine reacts with organic compounds to form trihalomethanes, which are chlorination byproducts used to remove harmful microorganisms (Zhao et al., 2017). However, long-term exposure to these compounds is harmful to human health, including bladder cancer, colon cancer, and colorectal cancer, as well as human immunity (Tounsadi et al., 2020).

Several dyes, particularly azo dyes, have mutagenic potential. In this regard, Sudan I, an azo-lipophilic dye used in the textile and food industries, was discovered to be enzymatically converted into carcinogenic aromatic amines by the action of intestinal microorganisms. Both the dye and its metabolites have the potential to cause cancer (Piątkowska et al., 2018). The Disperse Red 1 dye was also found to be mutagenic in human hepatoma (HepG2) cells and human lymphocytes due to its ability to increase the frequency of micronuclei, which is indicative of mutagenic activity at the chromosome level (Will et al., 2016). Furthermore, the Disperse Orange 1 dye causes DNA damage by causing base-pair replacement and frameshift mutations that change the reading frame (Chequer et al., 2009). When Disperse Orange 1 dye comes into contact with HepG2 cells, it has a cytotoxic effect, causing apoptosis (Ferraz et al., 2011). Direct Blue 14 dye was shown to form a carcinogenic amine when exposed to bacterial species found on human skin, whereas other dyes, such as Disperse Yellow 7, have been degraded in natural waterways, yielding amines, which are known carcinogenic agents (Balakrishnan et al., 2016).

Azure B (the major metabolite of Methylene Blue) is a cationic dye that can intercalate with the helical structure of DNA and duplex RNA (Haq and Raj, 2018). This dye may also be partitioned to the lipid membrane of animal cells, where it can cause harm by acting as a significant reversible inhibitor of monoamine oxidase A, an intracellular enzyme of the central nervous system that is important in human behavior (Li et al., 2014). The ability of Azure B to inhibit enzymes such as glutathione reductase, which is essential for cellular redox equilibrium, was also investigated (Couto et al., 2016). Triphenylmethane dyes, on the other hand such as Basic Red 9, which are used in the textile, leather, paper, and ink industries, are carcinogenic to humans because they produce aromatic amines during dye degradation under anaerobic conditions, resulting in allergic dermatitis, skin irritation, mutations, and cancer (Sivarajasekar and Baskar, 2014). Crystal Violet (triarylmethane dye) causes mitotic poisoning, resulting in chromosomal damage and abnormal metaphase accumulation (Mani and Bharagava, 2016). This highly carcinogenic substance has been linked to reticular cell sarcoma in a variety of organs, including the vagina and bladder (Lellis et al., 2019). Furthermore, Crystal Violet has the potential to cause chemical cystitis, skin and digestive system irritation, as well as respiratory and renal failure in humans (Mani and Bharagava, 2016).

More than 100 of the 4000 dyes tested for toxicity are still on the market despite the prohibited agreements, with the potential to create carcinogenic amines (Lacasse and Baumann, 2012). Small-scale textile factories around the world that secretly dump poisonous dyes into waterways because of export demand for cheap labor are under threat. There are opportunities offered by bioremediation technologies that are closely linked with a commitment to sustainable development in the face of this complex problem, which poses profound risks to ecosystems and humans alike. In other words, eco-friendly economic growth and improved human well-being are both promoted by bioremediation technologies.

3. Various technologies and methodologies used for the treatment of textile dye-containing wastewater

Obtaining clean drinking water is one of the major global concerns influencing people today, owing to anthropogenic activities and insecure access. By 2030, approximately 47% of the world's population will face the challenge of clean water scarcity (Islam et al., 2021). Therefore, the case for eliminating microorganisms and organic pollutants such as textile dyes is gaining popularity around the world in order to achieve the goal of having safe and clean drinking water. Unfortunately, for most middle- and low-income countries the resources needed for cleaning water are expensive, and therefore not feasible. The textile industry contributes to global economic growth, with China, the European Union, India, and the United States being the largest exporters of all textile types (Atkar et al., 2021; Darwesh et al., 2021). China has emerged as a major textile producer, accounting for nearly 55% of global textile consumption (Islam et al., 2021). Over 10,000 different synthetic dyes and pigments are widely used in the textile and paper industries, which has a significant negative impact on both the environment and human health (Al-Tohamy et al., 2020a, 2020b; Ali et al., 2021a, 2022). Cellulosic materials (for example, cotton, rayon, and linen derived from plants), protein fabrics such as silk, wool, and mohair, and synthetic fabrics such as nylon, acrylic, and polyester can all be produced in textile factories using wet and dry methods (Ali et al., 2021b, 2021c). The washing cycle is the final stage in the textile coloring process, resulting in the elimination of excess color and pigments that are discharged into water, thereby adding to water pollution (Tounsadi et al., 2020; Wu

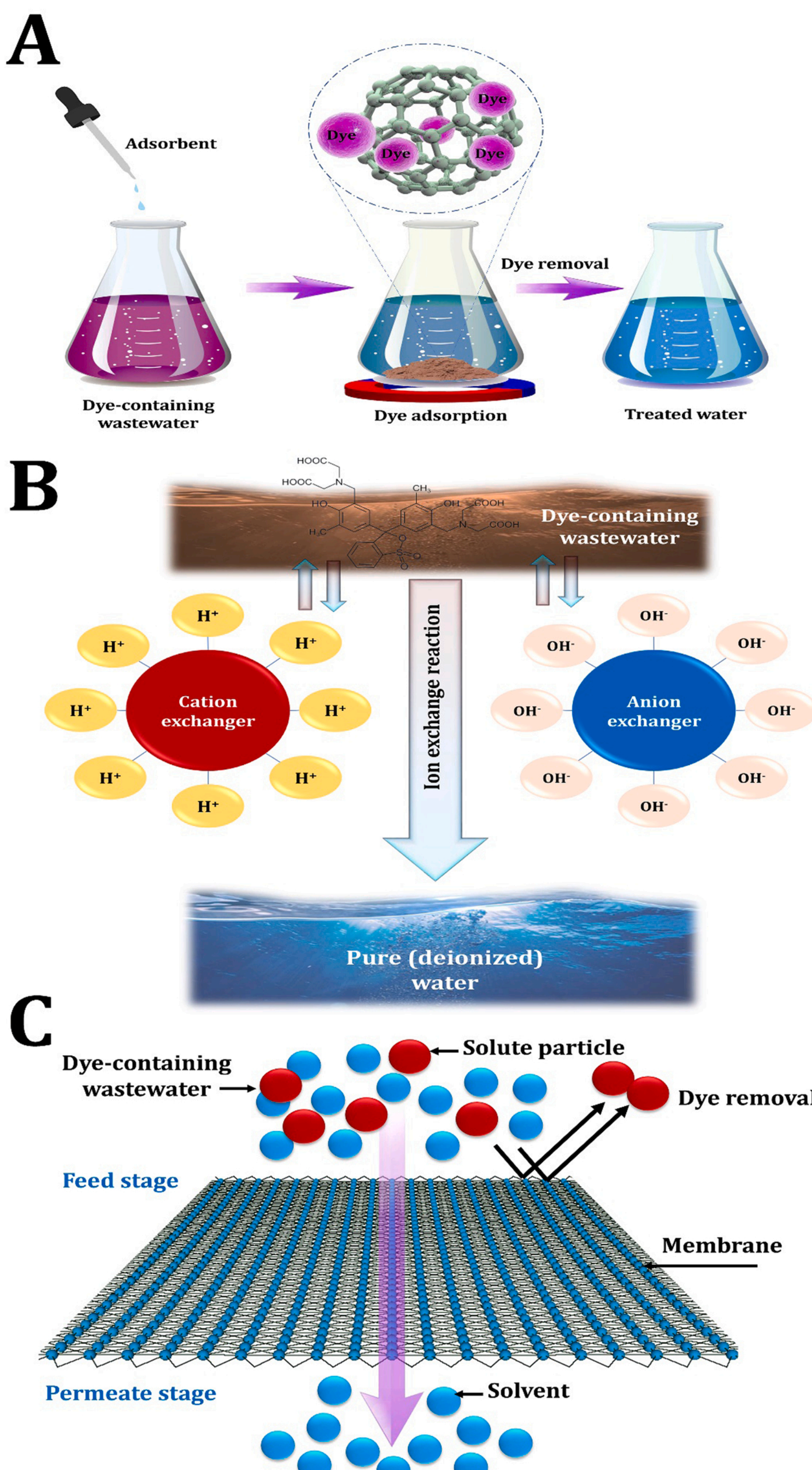

Fig. 6. Physical approaches for textile dye wastewater treatment, including dye adsorption with activated carbon (A), ion exchange (B), and membrane filtration (C).

et al., 2021) as it contains dyes with various chromophoric groups that are extremely toxic and potentially carcinogenic (Ali et al., 2020, 2021d, 2021e). Furthermore, textile dyes discharged into water remain in the environment and ground water resources for long periods of time. As a result, developing a process that can be sustained is critical to advancing color removal technology.

There is still no international consensus on the release of dye-containing wastewater and their textile effluents, including azo dyes, in terms of legislation. Generally, restrictions on azo dyes are not specified separately from those on physical and chemical characteristics of treated wastewater. Based on the wastewater properties, it can be treated physically, chemically, biologically, or utilizing a combination of these methods. The following are some of the most commonly used approaches.

3.1. Physical approaches for textile dye wastewater treatment

Based on the mass transfer mechanism, various physical approaches such as adsorption, ion exchange, and membrane filtration are used to treat dye-containing wastewater (Fig. 6), with a very high removal efficiency ranging from 85% to 99% (Samsami et al., 2020). Physical approaches have numerous advantages, including a simple design, ease of operation, low cost, fewer chemical requirements, and the presence of toxic substances has no inhibitory effect (Cao et al., 2021; Behera et al., 2021). However, these methods are frequently not preferred due to a number of drawbacks, including toxic byproducts and sludge production, as well as limited applicability (Akpomie and Conradie, 2020). Furthermore, high temperatures, chemical oxygen demand (COD), biological oxygen demand (BOD), pH, color, and heavy metals frequently hinder their application in textile wastewater treatment.

3.1.1. Adsorption

Adsorption is a surface-based process in which adsorbed molecules or ions are attracted to a solid adsorbent surface (Fig. 6A). There are two types of adsorption: physisorption and chemisorption. This classification is based on the manner by which the dye molecule is adsorbed onto the adsorbent surface (Burakov et al., 2018). In the adsorption of dye molecules, several forces such as van der wall forces, hydrophobic and electrostatic interactions, and hydrogen bonding may exist (Mudhoo et al., 2020). The advantages of the adsorption process include reusability of adsorbents, high efficiency, and a short time required for dye removal from wastewater (Li et al., 2019a; Akpomie and Conradie, 2020). The concept of adsorption is based on adsorbents, which commonly have porous structures that increase the total exposed surface area required for the fast and efficient adsorption of dye molecules from wastewater (Samsami et al., 2020; Abu-Nada et al., 2021). Several adsorbents, including zeolites, alumina, silica gel, and activated carbon, have been widely used for dye removal from wastewater. The activated carbon, on the other hand, is widely used adsorbent on an industrial scale (Jadhav and Jadhav, 2021). The Biopolymer/ZSM–5 zeolite adsorbent was used to treat dye-containing wastewater such as Crystal Violet (15 mg/L; pH 7.5), Basic Fuchsin (15 mg/L; pH 9.0), and Methylene Blue (15 mg/L; pH 8.0), with decolorization percentages of 75.3, 81.2, and 86.6, respectively (Brião et al., 2018). Using ZnO@Ze composite particles as an adsorbent at a dye concentration of 25–500 mg/L and an adsorbent dose range of 0.025–0.1 g/L, up to 90% Congo Red decolorization was achieved (Madan et al., 2019).

3.1.2. Ion exchange

The ion exchange method has recently received great attention in the treatment of textile wastewater and effluents due to its advantages, such as low cost, regeneration, simplicity, flexibility, and high efficiency. Effective separation in the ion exchange method is achieved by generating strong bonds between the resins used in a packed bed reactor and the solutes (Akpomie and Conradie, 2020). The mechanism of ion exchange in dye removal, as shown in Fig. 6B, is based on strong interactions between the functional groups of resins and the charges on dye molecules (Ahmad et al., 2015). At a dye concentration of 10^{-2} M, the anion-exchange resin (Amberlite IRA 400) was used to remove Acid Orange 10 from wastewater, achieving a dye removal of 97% (Marin et al., 2019), while at a dye concentration of 10–500 mg/L, a resin cation exchanger removed 91.7% of Disperse Violet 28 (Bayramoglu et al., 2020).

3.1.3. Membrane filtration

Membrane filtration, as one of the cutting-edge physical technologies, is used for the treatment of dye-containing wastewater. Because the membranes used in this method have small pores, solutes larger than these pores become trapped behind them, resulting in a dye-free solution (Fig. 6C). Although this technique is simple and effective, the membranes need periodic replacement (Samsami et al., 2020). Microfiltration (MF) is a membrane-based filtration process that uses a typical membrane with pore sizes ranging from 0.1 to 10 μm to separate suspended particles and dyes from wastewater (Cheryan, 1998). Nanofiltration (NF) is another advanced membrane technology that has recently been used for the treatment of dye-containing wastewater, with typical membranes ranging in diameter from 0.5 to 0.2 nm (Behera et al., 2021). As a result, nanofiltration technology can separate dye molecules from wastewater solutions using size and electrostatic repulsion mechanisms (Dasgupta et al., 2015a). Ultrafiltration (UF) membranes can also be used to remove organic dyes from textile wastewater, with membrane diameters ranging from 0.1 to 0.001 μm. Although ultrafiltration is less expensive and requires less pressure than nanofiltration, the separation rate is low due to the large membrane pore size (Dasgupta et al., 2015b). Reverse osmosis (RO) is a membrane filtration process that has significant industrial applications in the treatment of dye-containing wastewater and thus provides high quality water (Wang et al., 2020a, 2020b). The advantages of RO technology include the ability to achieve concentration and separation with no state change or thermal energy (Liang et al., 2021).

3.2. Chemical approaches for textile dye wastewater treatment

Chemical approaches such as coagulation-flocculation, electrochemical, and advanced oxidation processes are used to treat dye-containing wastewater (Fig. 7). Except for electrochemical technology, these methods are typically more expensive than physical and biological approaches. Furthermore, the main disadvantages for commercial use of chemical approaches for dye removal from textile wastewater are the high electrical energy requirements, large amounts of used chemicals, and the requirement of proper equipment (Kishor et al., 2021). The use of chemical approaches for dye removal also pose additional challenges due to the toxic metabolites and by-products formed during the treatment process (Katheresan et al., 2018; Wang et al., 2020a, 2020b).

3.2.1. Coagulation-flocculation

Wastewater typically contains a high concentration of impurities and toxins. Hence, it can be treated prior disposal with coagulants. In this treatment technique, metal salts and polymers can be used as coagulants, while flocculants are polymers that increase the aggregation of flocs so that they can be separated more easily (Al-Mutairi, 2006). The coagulants are added during the vigorous mixing stage. The charge of finely dispersed particles is then neutralized or reduced as a result of the presence of coagulants. Finally, the flocculants are mixed with the fine particles to form large particles that can be easily separated by sedimentation (Mahmudabadi et al., 2018). Fig. 7A illustrates the schematic diagram of coagulation-flocculation approach for the treatment of dye-containing wastewater. Tamarindus indica and Azadirachta indica have been reported as highly effective natural coagulants for dye removal from industrial wastewater effluents (Mathuram et al., 2018). In the coagulation-flocculation approach, several chemical coagulants were also used. Iron coagulants such as ferric chloride, ferrous sulfate,

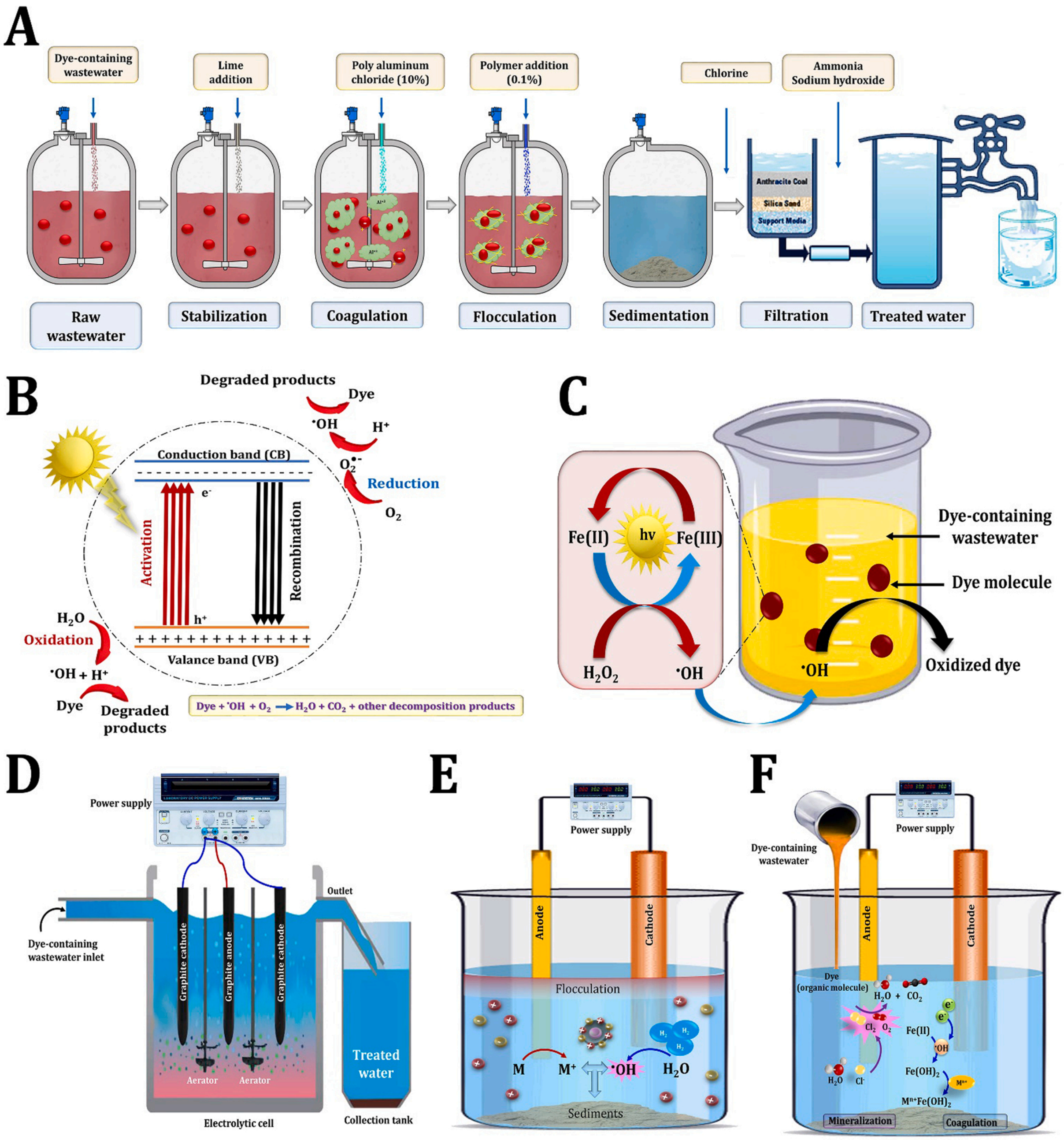

Fig. 7. Chemical approaches for textile dye wastewater treatment, including coagulation-flocculation (A), photocatalytic degradation of toxic dye molecules (B), photo-Fenton (C), electro-Fenton (D), electrocoagulation (E), and anodic oxidation approach (F).

and ferric chloride sulfate are usually added to maintain the purity of the removal system, while other chemical coagulants such as magnesium carbonate and hydrated lime are required for adsorbing azo dyes and their byproducts (Li et al., 2018; Dotto et al., 2019; Badawi and Zaher, 2021). When a coagulant is applied to a solution and vigorously mixed, it precipitates, trapping organic contaminants and impurities. These precipitated compounds can then be filtered physically to provide treated clean water. The use of laterite soil as a strong flocculant and coagulant, rich in iron and aluminum, significantly reduced Acid Orange 7 up to 98% (Lau et al., 2014). This approach is both cost effective and essential for the treatment of dye-containing textile wastewater. However, it has the disadvantages of being pH dependent and producing concentrated sludge (Samsami et al., 2020).

3.2.2. *Advanced oxidation approaches*

Several technologies for the treatment of dye-containing wastewater have been investigated. Advanced oxidation, one of these approaches, has been used in this regard, and its hypothesis is based on the *in-situ* generation of hydroxyl radicals ($OH^{\bullet}$), which are powerful oxidizing agents used to treat dye-containing wastewater (Rahmani et al., 2019). Photocatalysis, Fenton, photo-Fenton, ozonation, and electrochemical oxidation processes are examples of advanced oxidation methods. These methods are capable of removing dye under harsh conditions quickly and without the formation of sludge. They do, however, have the disadvantages of being expensive, pH dependent, and producing toxic by-products (Zhao et al., 2022).

The production of $OH^{\bullet}$ alongside with textile wastewater degradation have been studied extensively using the photocatalysis process (Li et al., 2020; Abdel-Moniem et al., 2021). The mechanism of the $OH^{\bullet}$

generation for photocatalytic degradation of toxic dye molecules is depicted in Fig. 7B. Nanoparticles such as zinc oxide and titanium peroxide are used as photocatalytic agents to generate free radicals and holes, both of which are required for dye degradation *via* photocatalysis (Siwińska-Stefańska et al., 2018). By oxidizing the organic dye molecules, the holes produced mineralization products and $OH^{•}$, while electrons as reducing agents produced superoxide (Hassanshahi and Karimi-Jashni, 2018).

Fenton and photo-Fenton processes are two of the most widely used advanced oxidation methods for the degradation of organic pollutants in wastewater, such as dye molecules (Xiang et al., 2020; Zhong et al., 2021) as given in Fig. 7C. This approach is based on the presence of a Fenton's reagent (H_2O_2) and soluble iron (II) salt mixture (Saratale et al., 2019). The formation of $OH^{•}$ is the first stage in the Fenton method (Eq. 1), and it occurs in the photo-Fenton process, as shown in the following Eqs. (2 and 3). To treat dye-containing wastewater, the $OH^{•}$ radical can also be formed during the ozonation process (Gagné et al., 2008; He et al., 2021). This procedure is carried out in three stages: initiation (Eq. 4), propagation (Eqs. 5 and 6), and termination (Eqs. 7 and 8). Electrochemical technology, a new advanced oxidation approach for the treatment of dye-containing wastewater, has recently been developed (Li et al., 2019a, 2019b, 2019c, 2019d, 2019e). Photoelectrocatalysis produces $OH^{•}$ radicals at the anode surface in electrochemical technology. $OH^{•}$ radicals, on the other hand, are produced in anodic oxidation *via* electro-Fenton or sonoelectrolysis (Mojiri et al., 2018).

$$Fe^{2+} + H_2O_2 \rightarrow OH^{•} + Fe^{3+} + OH^{-} \tag{1}$$

$$UV + H_2O_2 \rightarrow 2OH^{•} \tag{2}$$

$$Fe^{3+} + UV + H_2O \rightarrow OH^{•} + Fe^{2+} + H^{-} \tag{3}$$

$$H_2O + O_3 + h\upsilon \rightarrow O_2 + 2OH^{•} \tag{4}$$

$$OH^{•} + O_3 \rightarrow O_2 + HO_2^{•} \tag{5}$$

$$HO_2^{•} + O_3 \rightarrow 2O_2 + OH^{•} \tag{6}$$

$$HO_2^{•} + OH^{•} \rightarrow O_2 + H_2O \tag{7}$$

$$2OH^{•} \rightarrow H_2O_2 \tag{8}$$

3.2.3. Electrochemical approaches

In recent years, three techniques have been used to remove organic pollutants from wastewater, such as textile dyes. Electrocoagulation, electro-Fenton, and anodic oxidation are three of these methods. Electrochemical treatment technologies do not require the addition of chemicals and produce no sludge. However, the disadvantages of such approaches include high electricity costs and being less effective than other treatment technologies (Palas et al., 2019; Yadav et al., 2019; Dória et al., 2020; Zhang et al., 2021). Organic pollutants can be removed using two combined processes of oxidation and coagulation in the electro-Fenton, which is considered one of the most widely advanced oxidation approaches used in practice (Fig. 7D). This method is distinguished by the absence of toxic byproducts, the preservation of the environment, and the use of fewer chemicals (Khataee et al., 2009). The electrocoagulation approach employs two metallic electrodes for direct power supply as well as the formation of *in-situ* coagulant particles, and the electrocoagulation mechanism employed for the treatment of dye-containing wastewater, as previously reported by Sharma and Verma (2017), is depicted in Fig. 7E. The iron metal anode serves as a catalyst and coagulant agent, while the cathode generates hydrogen gas. This method is distinguished by its low sludge production, low cost, ease of operation, and lack of chemical requirements (Hamad et al., 2018; Samsami et al., 2020). Anodic oxidation (Fig. 7F) is another type of electrochemical techniques that is used to remove organic pollutants from wastewater *via* direct/indirect processes (Montañés et al., 2020). In the direct oxidation process, organic compounds are adsorbed at the anode's surface and then degraded by the anodic electron transfer mechanism. Strong oxidants, on the other hand, such as O_3 and H_2O_2, are produced electrochemically *via* the indirect oxidation process. This method is distinguished by the efficient removal of dyes and other organic pollutants. However, it has a number of drawbacks, including high operational costs and low stability (Hamad et al., 2018).

3.3. Biological approaches for textile dye wastewater treatment

Biological approaches for the treatment of dye-containing wastewater are more promising than physical and chemical techniques because they are more easily applicable, generate less sludge, require fewer chemical reagents, are less expensive, have energy-saving features, are more environmentally safe, and the byproducts generated during microbial metabolic activity are non-toxic (Ali et al., 2019, 2020, 2021d, 2022). Furthermore, biological approaches are economically feasible for use in developing countries and result in complete dye mineralization (Coria-Oriundo et al., 2021). The primary goal of biological treatment is to convert recalcitrant organic dyes into non-toxic products. The main advantage of the biological treatment is the use of microorganisms with a high biodegradable ability where dye-containing wastewater, either singly or in consortia is concerned (Liu et al., 2018). Adsorption and degradation are the two main processes used for dye decolorization treatment of textile wastewater (Popli and Patel, 2015). These processes take place under aerobic or anaerobic conditions, as the products of aerobic treatment are biomass, carbon dioxide, and water, whereas the main product of anaerobic treatment is methane (Kamali and Khodaparast, 2015; Chen et al., 2021a, 2021b). Bacteria, algae, yeast, and fungi, as well as enzyme-based systems, are all viable biological candidates for the treatment of textile dye wastewater, converting dye molecules into non-toxic products (Al-Tohamy et al., 2020a; Khan et al., 2020; Coria-Oriundo et al., 2021). The attractive force creation property of the microbial cell wall and the azo dye present in wastewater is attributed to the various groups of microbial cell wall components such as amino, carboxyl, hydroxyl, phosphate, and other charged groups (Jafari et al., 2014).

3.3.1. Enzyme-assisted degradation of dye-containing wastewater

Due to their high cost, pure enzymes are not the first choice for the treatment of dye-containing wastewater. Industrial enzymes, on the other hand, stand out because of their low cost, efficiency, reliability, and they are available in liquid form (Dawkar et al., 2010; Li et al., 2019a, 2019b, 2019c, 2019d, 2019e). Laccases and azo reductases, for example, are effective at degrading azo dye-containing wastewater, converting such complex organic pollutants into simple products, and removing them from textile wastewater *via* flocculation (Samsami et al., 2020). As a result, enzymes are widely used in the chemical and biotechnological industries. However, one of the most difficult aspects of enzymatic degradation is biocatalyst deactivation due to denaturation (Jun et al., 2019). Several studies have recently been carried out to determine the activity of various enzymes during the degradation of azo dyes (Riegas-Villalobos et al., 2020), out of these the oxidoreductase enzyme class is the one that has been extensively studied. Peroxidase enzymes are the most widely available against a wide range of industrial dyes, with higher temperature tolerance and a wider operating pH range (Mishra and Maiti, 2019).

Enzyme immobilization emerges as a promising aspect in textile dye biodegradation, with immobilization strategies making significant progress, improving enzyme performance in various applications (Amer et al., 2022; Basak et al., 2019). Cross-linking is a commonly used immobilization tool due to its compatibility and efficacy with almost any type of enzyme (Matto and Husain, 2009; Buscio et al., 2016). To immobilize dye-degrading enzymes, a variety of products, including charcoal or biochar pellets and calcium alginate gel capsules, can be used. Malani et al. (2013) used immobilized horse radish peroxidase (HRP) and a sono-enzymatic combined treatment approach to improve azo dye (e.g., Acid Red) decolorization, achieving up to 61%. Furthermore, an azoreductase-glucose-1-dehydrogenase enzyme system with 85% azoreductase activity has been developed for the degradation of azo dyes (Yang et al., 2013). Misra et al. (2014) investigated enzyme activity during Acid Red-1 degradation by immobilizing the laccase enzyme on epoxy-functionalized polyether sulfone beads, which degraded 88% of the dye at a concentration of 10 mg dye/L in 15 days. Furthermore, Bilal et al. (2017) investigated the dye decolorization efficiency of chitosan encapsulated HRP in a packed bed reactor, finding decolorization of Remazol Brilliant Blue R, Crystal Violet, Congo Red, and Reactive Black-5 of 82.17%, 87.43%, 94.35%, and 97.82%, respectively. The enzyme's resistance to heavy metal inhibition was also improved by this immobilization system. Moreover, Bilal et al. (2019) investigated the degradation of the Reactive Blue 19 dye by HRP immobilized on an eco-friendly support material made of agarose–chitosan hydrogel. Under alkaline conditions, the immobilized enzyme system had 1.6- and 400-fold greater catalytic activity than the free/soluble enzyme system at 50 and 70 °C, respectively. Finally, ionic liquids can be used to improve dye degradation, as shown by Indigo Carmine *via* laccase, which demonstrated 82% degradation in 30 min (Bento et al., 2020).

Entrapping enzymes on a suitable matrix can improve dye treatment efficacy as well as biodegradability and stability. In contrast, the applied enzyme activity varies depending on the enzyme's class, source, and substrate. Furthermore, the efficiency of dye decolorization demonstrated by immobilized enzymes was found to be greater than that of soluble enzymes, despite the fact that immobilization allows the enzyme to be reused multiple times (Britos et al., 2018). Furthermore, temperature, pH, salt concentration, co-substrate, and electron donor all have an impact on the dye decolorization process, which must be optimized in order to achieve a high decolorization response. However, single enzymes such as manganese peroxidase, azoreductase, and other related enzymes can generate intermediate compounds such as amino acids and phenols that are more toxic than the parent dye compounds during the dye degradation process (Mishra and Maiti, 2019). A combination of two or more oxidoreductase enzymes could be used in this case to convert toxic intermediates into insoluble end-products (Mishra and Maiti, 2019). However, the use of enzymes to decolorize dyes necessitates additional research to demonstrate the application of enzyme combinations and to develop a cost-effective method for treating dye-containing wastewater.

3.3.2. *Bacteria-assisted degradation of dye-containing wastewater*

Many bacterial species have been shown to be more efficient at degrading dye-containing wastewater than other microorganisms (Guo et al., 2020; Liu et al., 2021). The efficacy of dye degradation by bacteria is determined by the bacteria's adaptability and ability to degrade dye under the prevailing environmental conditions (Chen et al., 2021a, 2021b). Many bacterial species have been shown to be capable of azo dye biodegradation, including *Klebsiella*, *Pseudomonas*, *Bacillus*, *Rhodococcus*, and *Shigella* (Ali et al., 2019; Guo et al., 2020; Chen et al., 2021a, 2021b). The main advantages of using bacteria in dye degradation are their ease of cultivation, high specific growth rates when compared to other microorganisms as well as their versatile catalytic capability for mineralizing azo dyes present in wastewater (Kamali and Khodaparast, 2015; Mudhoo et al., 2020). As the first stage of the bacterial degradation mechanism, various bacterial species have used azo reductase enzymes to biodegrade azo dyes under aerobic or anaerobic conditions *via* azo bond cleavage (Pearce et al., 2006).

Table 1 depicts the bacteria-assisted degradation of dye-containing wastewater. Bacterial decolorization of azo dyes frequently occurs *via* azo bond reduction under anaerobic conditions, leading to the production of colorless amino acids (Brüschweiler and Merlot, 2017). These derived compounds, however, are mutagenic and carcinogenic,

Table 1
Biodegradation of textile dyes by various microorganisms.

Microorganism	Dye	Dye removal (%)	References
Bacteria-based dye degradation			
Aeromonas hydrophila	Red RBN	> 90	Chen et al. (2003)
Pseudomonas aeruginosa NBAR12	Reactive Blue 172	83	Bhatt et al. (2005)
Enterococcus gallinarum	C.I. Direct Black 38	53–63	Bafana et al. (2008)
Micrococcus glutamicus NCIM-2168	C.I. Reactive Green 19A	100	Saratale et al. (2009)
Pseudomonas sp. SUK1	Reactive Red 2	80	Kalyani et al. (2009)
Bacillus sp. VUS	Navy Blue 2GL	~90	Dawkar et al. (2009)
Kocuria rosea MTCC 1532	Methyl Orange	100	Parshetti et al. (2012)
Proteus mirabilis LAG	Reactive Blue 13	87.91	Olukanni et al. (2010)
Lysinibacillus sp. RGS	C.I. Remazol Red	100	Saratale et al. (2013)
Lysinibacillus sp. KMK-A	Reactive Orange M2R	98	Chaudhari et al. (2013)
Bacillus cereus	Orange II /Acid Orange 7	52.5	Garg, and Tripathi (2013)
Pseudomonas extremorientalis BU118	Congo Red	36–94	Neifar et al. (2016)
Fungi-based dye degradation			
Rhizophus arrhizus	Remazol Brilliant Blue R	86.9	Aksu and Tezer (2000)
Penicillium oxalicum	Reactive Blue 19	91	Zhang et al. (2003)
Irpex lacteus	Reactive Orange 16	95	Novotný et al. (2004)
Neurospora crassa	Acid Red 57	98.78	Akar et al. (2006)
Aspergillus sp.	Brilliant Green	99.27	Kumar et al. (2012)
Aspergillus niger	Red azo dye	99.69	Mahmoud et al. (2017)
Peroneutypa scoparia	Acid Red 97	75	Pandi et al. (2019)
Yeast-based dye degradation			
Phormidium sp.	Reactive Black B	60	Ertuğrul et al. (2008)
Galactomyces geotrichum MTCC1360	Methyl Red	100	Jadhav et al. (2007)
Trichosporon beigelii NCIM-3326	Navy Blue HER	100	Saratale et al. (2009)
Candida tropicalis	Acid Blue 93	100	Deivasigamani and Das (2011)
Galactomyces geotrichum MTCC1360	Mixture of dyes	88	Waghmode et al. (2011)
Candida krusei	Basic Violet 3	100	Deivasigamani and Das (2011)
Trametes trogii BAFC463	Fast Blue RR	> 85	Grassi et al. (2011)
Pichia sp. TCL	Acid Red B	90	Qu et al. (2012)
Magnusiomyces ingens LH-F1	Acid Red B	97.37	Tan et al. (2014)
Scheffersomyces spartinae TLHS-SF1	Acid Scarlet 3R	98.14	Tan et al. (2016)
Trichosporon akiyoshidainum HP2023	Reactive Black 5	89	Martorell et al. (2017)
Sterigmatomyces halophilus SSA1575	Reactive Black 5	100	Al-Tohamy et al. (2020a)
Algae-based dye degradation			
Chlorella vulgaris	Remazol Brilliant Blue R	53.2	Aksu and Tezer (2005)
Scenedesmus bijugatus	Tartrazine	68	Omar (2008)
Coelastrella sp.	Rhodamine B	80	Baldev et al. (2013)
Dermatocarpon vellereceum	Navy Blue HE22	95	Kulkarni et al. (2018)
Chara vulgaris L.	Methyl Red	70–100	Patil et al. (2015)

necessitating an additional aerobic stage of bacterial degradation to reduce their toxicity and transform them into environmentally friendly compounds (Franca et al., 2020). Decolorization of Reactive Orange M2R with *Lysinibacillus* sp. KMK-A was attributed primarily to azo bond reduction and metabolite formation, and thus the rate of dye decolorization can be measured in terms of BOD and COD reduction. These two parameters are important for the determination of the organic load and the degree of mineralization (Chaudhari et al., 2013).

Bacteria have demonstrated up to 100% efficiency in dye-containing textile wastewater biodegradation, and bacterial consortia frequently outperform a single strain in dye removal effectiveness (Liu et al., 2018; Ali et al., 2019; Guo et al., 2020). Tony et al. (2009) developed SKBII, a bacterial consortium containing five strains of different *Bacillus* species, including, *B. megaterium*, *B. vallismortis*, *B. cereus*, *B. pumilus*, and *B. subtilis*, that was more effective at dye decolorization than the individual strains. Furthermore, Phugare et al. (2011) compared the ability of a bacterial consortium containing *Pseudomonas aeuroginosa* BCH and *Providencia* sp. SDS, isolated from dye-contaminated soil, to degrade Red HE3B to individual strains. It was demonstrated that decolorization and degradation were much faster in the case of the consortium than in the case of individual bacterial strains, and the consortium's intensive metabolic activity resulted in 100% decolorization of 50 mg/L of Red HE3B dye within 1 h. Mohanty and Kumar (2021) investigated the decolorization of Indanthrene Blue RS using a bacterial consortium BP constructed from *Bacillus flexus* TS8, *Proteus mirabilis* PMS, and *Pseudomonas aeruginosa* NCH isolated from textile wastewater and dye-contaminated soil. In comparison to the individual strains, the BP consortium demonstrated improved dye decolorization with an average decolorization rate of 11,088 g/h over a 9-hour period, while the addition of residual agricultural wastes improved the BP decolorization performance. The oxidoreductive enzymes were involved in the overall degradation mechanism, with increased intracellular enzyme concentrations and non-toxic generated metabolites (Mohanty and Kumar, 2021). As a result, it can be concluded that a variety of individual bacterial strains and bacterial consortia are capable of biodegrading a variety of dyes used in textile manufacturing. This environmentally friendly approach is promising for dye-containing wastewater treatment and may represent a novel and advanced strategy for large-scale dye decolorization.

3.3.3. Fungal-assisted degradation of dye-containing wastewater

Fungi, through various fungal strains or consortia, play an important role in the degradation and mineralization of a wide range of textile dyes. The primary advantage of using fungi for dye-containing wastewater treatment is the ability to accelerate their metabolism in order to achieve optimal environmental conditions (Zafiu et al., 2021). Intracellular and extracellular enzymes, such as manganese peroxidase, laccase, and lignin peroxidase, can boost their metabolic activity and help with the treatment of dye-containing wastewater (Khan et al., 2020). Since the early 1990s, the contribution of white-rot fungi to the degradation of recalcitrant organic pollutants, including azo dyes, has been revealed due to their non-specific lignin-modifying enzymes (Zafiu et al., 2021). Table 1 depicts the fungal-assisted degradation of dye-containing wastewater. *Phanerochaete chrysosporium* can be used to degrade a mixture of pollutants from wastewater from textile, pulp, and paper industries that contain polycyclic aromatic hydrocarbons (Senthilkumar et al., 2014). After six days of cultivation, *Aspergillus niger* successfully biodegraded Congo Red with a high decolorization efficiency of 97%, demonstrating that only 1.0 g of fresh biomass can remove 27% of Congo Red through biosorption, while the biodegradation process can remove 70% of dye due to the combined action of manganese peroxidase, lignin peroxidase, and possibly deaminase (Asses et al., 2018). Laccase, a fungal enzyme, has been shown to remove 70–88% of dye molecules, and in some cases, manganese peroxidase, lignin peroxidase, and laccase have been combined to degrade dye molecules (Bankole et al., 2018). It has been reported that depending on the processing medium, fungi can produce a wide range of oxidative enzymes (Noman et al., 2020).

3.3.4. Yeast-assisted degradation of dye-containing wastewater

Yeasts have several advantages over filamentous fungi and bacteria, when it comes to degrading textile dyes. Due to their rapid growth rates and ability to tolerate adverse environmental conditions such as low pH, yeasts have the potential to be used as a substitute for the treatment of dye-containing wastewater (Khan et al., 2013; Ali et al., 2018, 2020). However, only a few reports highlight dyes degradation and removal by yeasts (Jamee and Siddique, 2019; Ali et al., 2021a, 2022). Several ascomycetous yeast species have been known to degrade dye-containing wastewater, including *Debaryomyces*, *Candida*, *Kluyveromyces*, and *Saccharomyces*. *Trichosporon* and *Rhodotorula*, on the other hand, are the most promising basidiomycetous yeast genera (Samsami et al., 2020; Al-Tohamy et al., 2021c). Several yeasts, including *Scheffersomyces spartinae*, *Pichia occidentalis*, and *Sterigmatomyces halophilus*, have demonstrated the ability to degrade textile dyes, including azo dyes (Tan et al., 2016; Al-Tohamy et al., 2020a, 2020b), as well as tolerate harsh conditions, such as high salt concentrations in textile wastewater. Table 1 depicts the yeast-assisted degradation of dye-containing wastewater. Biosorption and reductive azo bond cleavage are the primary pathways by which yeast strains can remove high concentrations of different dyes from wastewater. Yeasts frequently decolorize textile dyes such as Remazol Brilliant Blue, Congo Red, Malachite Green, Acid Red B, Reactive Black 5, and Rhodamine B (Ertuğrul et al., 2008; Aghaie-Khouzani et al., 2012; Al-Tohamy et al., 2020b).

In terms of dye degradation by yeasts, 12 strains, including *Saccharomycopsis lipolytica*, *Saccharomyces uvarum*, *Saccharomyces cerevisiae*, and *Torulopsis candida*, removed the dye Reactive Brilliant Red K-2BP *via* biosorption (Yu and Wen, 2005). *Saccharomyces cerevisiae* was also evaluated for its ability to remove Ramazole Blue, with results indicating that it can reduce the color absorbance and COD of real textile wastewater by 100% and 61.82%, respectively, *via* biosorption (Mahmoud, 2016). Ruscasso et al. (2021) investigated the potential use of an Antarctic yeast's biomass, *Debaryomyces hansenii* F39A, as a biosorbent for the textile dyes Reactive Red 141 and Reactive Blue 19. The obtained results showed that the dye concentration dropped dramatically in the first 15 min of the operation, while no harmful toxic compound was released as a result of adsorption. It can be concluded that using biomass from selected yeasts as a biosorbent can be a viable, cost-effective, and efficient alternative to using expensive materials like activated carbon (Ruscasso et al., 2021).

3.3.5. Algae-assisted degradation of dye-containing wastewater

Algae have gained significant interest as bio-coagulants for textile dyes biodegradation due to their ideal cell wall properties, large surface, high capacity, and affinity for binding (An et al., 2020; Dória et al., 2020). Under standard atmospheric conditions, algal-based bioprocesses are typically simple to operate; they are also environmentally friendly and relatively inexpensive when compared to conventional treatment methods (Li et al., 2019b, 2019c; Samei et al., 2019). Furthermore, unlike bacteria and fungi, which require the addition of carbon and other components to remove dyes, algae do not (Omar, 2008). Table 1 depicts the algae-assisted degradation of dye-containing wastewater. Mohan et al. (2002) investigated the ability of Spirogyra to degrade azo dyes. El-Sheekh et al. (2009) also investigated *Oscillatoria rubescens*, *Lyngbya lagerlerimi*, *Elkatothrix viridis*, *Volvox aureus*, *Nostoc lincki*, and *Chlorella vulgaris* for decolorization of Methyl Red, Orange II, and Basic Fuchsin, with decolorization performance ranging from 4% to 95%. The degradation of algae-based dyes is primarily determined by the algal species used, their metabolic activity, and the molecular structures of the dyes. According to Abou-El-Souod and El-Sheekh (2016), the degradation of Basic Fuschin by *Oscillatoria limnetica* and *Hydrocoleum oligotrichum* after 7 days was 90.23% and 92.44%, respectively, while the degradation of Methyl Red by the same species was 50.18% and

53.23%. El-Sheekh et al. (2018) also investigated the biodegradability of the Cyanobacterium *Aphanocapsa elachista* and the green alga *Chlorella vulgaris*, which were isolated from contaminated industrial areas. After one week of incubation, 55% of decolorization was observed in Dispersed Orange 2 RL by *C. vulgaris* and 49% in Reactive Yellow 3 RN by *A. elachista* (El-Sheekh et al., 2018).

4. Conclusions and future perspectives

Water is the most essential component of life for all living organisms, and it is estimated that nearly 800 million people around the world still do not have access to safe drinking water of sufficient quality for domestic purposes. The rampant pollution of natural water resources by organic and inorganic pollutants has become an issue for many countries in recent years. A wide range of toxic xenobiotics are found at high concentrations in textile wastewater, which pose serious environmental and public health risks. Toxic dye-containing wastewater is a major problem because textile mills all over the world regularly discharge millions of gallons of highly polluted wastewater. Treatment of dye-containing wastewater, on the other hand, is a significant challenge because there is no specific and economically viable technique for adequately treating such a problem. Many traditional and emerging treatment approaches for dye-containing wastewater have been reported. Dye removal/degradation from dye-containing wastewater appears to be effective using physical and chemical methods. However, these approaches have high operating costs and produce undesirable byproducts. When compared to physical and chemical methods, the microbial approach to dye-containing wastewater remediation is more cost effective, environmentally friendly, and globally acceptable. However, one of the drawbacks of biological approaches is that they are less effective and should be administered over a long period of time. As a result, more research is required until an advanced, zero-waste process is established, as well as to minimize environmental and public health hazards during the transition from laboratory to pilot scale.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Abdel-Moniem, S.M., El-Liethy, M.A., Ibrahim, H.S., Ali, M.E., 2021. Innovative green/non-toxic Bi2S3@ g-C3N4 nanosheets for dark antimicrobial activity and photocatalytic depollution: turnover assessment. Ecotoxicol. Environ. Saf. 226, 112808.

Abou-El-Souod, G.W., El-Sheekh, M.M., 2016. Biodegradation of basic fuchsin and methyl red. Environ. Eng. Manag. J. 15 (2), 279–286.

Abu-Nada, A., Abdala, A., McKay, G., 2021. Removal of phenols and dyes from aqueous solutions using graphene and graphene composite adsorption: a review. J. Environ. Chem. Eng. 9, 105858.

Adomas, B., Sikorski, Ł., Bęś, A., Warmiński, K., 2020. Exposure of *Lemna minor* L. to gentian violet or Congo red is associated with changes in the biosynthesis pathway of biogenic amines. Chemosphere 254, 126752.

Aghaie-Khouzani, M., Forootanfar, H., Moshfegh, M., Khoshayand, M.R., Faramarzi, M. A., 2012. Decolorization of some synthetic dyes using optimized culture broth of laccase producing ascomycete *Paraconiothyrium variabile*. Biochem. Eng. J. 60, 9–15.

Ahmad, A., Mohd-Setapar, S.H., Chuong, C.S., Khatoon, A., Wani, W.A., Kumar, R., Rafatullah, M., 2015. Recent advances in new generation dye removal technologies: novel search for approaches to reprocess wastewater. RSC Adv. 5 (39), 30801–30818.

Akar, T., Demir, T.A., Kiran, I., Ozcan, A., Ozcan, A.S., Tunali, S., 2006. Biosorption potential of Neurospora crassa cells for decolorization of Acid Red 57 (AR57) dye. J. Chem. Technol. Biotechnol.: Int. Res. Process, Environ. Clean. Technol. 81 (7), 1100–1106.

Akpomie, K.G., Conradie, J., 2020. Advances in application of cotton-based adsorbents for heavy metals trapping, surface modifications and future perspectives. Ecotoxicol. Environ. Saf. 201, 110825.

Aksu, Z., Tezer, S., 2000. Equilibrium and kinetic modelling of biosorption of Remazol Black B by Rhizopus arrhizus in a batch system: effect of temperature. Process Biochem. 36 (5), 431–439.

Aksu, Z., Tezer, S., 2005. Biosorption of reactive dyes on the green alga Chlorella vulgaris. Process Biochem. 40 (3–4), 1347–1361.

Ali, S.K., Saleh, A.M., 2012. Spirulina-an overview. Int. J. Pharm. Pharm. Sci. 4 (3), 9–15.

Ali, S.S., Al-Tohamy, R., Sun, J., 2022. Performance of *Meyerozyma caribbica* as a novel manganese peroxidase-producing yeast inhabiting wood-feeding termite gut symbionts for azo dye decolorization and detoxification. Sci. Total Environ. 806, 150665.

Ali, S.S., Al-Tohamy, R., Koutra, E., El-Naggar, A.H., Kornaros, M., Sun, J., 2021e. Valorizing lignin-like dyes and textile dyeing wastewater by a newly constructed lipid-producing and lignin modifying oleaginous yeast consortium valued for biodiesel and bioremediation. J. Hazard. Mater. 403, 123575.

Ali, S.S., Al-Tohamy, R., Koutra, E., Kornaros, M., Khalil, M., Elsamahy, T., El-Shetehy, M., Sun, J., 2021a. Coupling azo dye degradation and biodiesel production by manganese-dependent peroxidase producing oleaginous yeasts isolated from wood-feeding termite gut symbionts. Biotechnol. Biofuels 14 (1), 61.

Ali, S.S., Al-Tohamy, R., Sun, J., Wu, J., Huang, M., 2018. The role of gut symbionts from termites: a unique hidden player from yeasts. Acta Microbiol. Sin. 58 (6), 1004–1015.

Ali, S.S., Al-Tohamy, R., Sun, J., Wu, J., Huizi, L., 2019. Screening and construction of a novel microbial consortium SSA-6 enriched from the gut symbionts of wood-feeding termite, *Coptotermes formosanus* and its biomass-based biorefineries. Fuel 236, 1128–1145.

Ali, S.S., Al-Tohamy, R., Xie, R., El-Sheekh, M.M., Sun, J., 2020. Construction of a new lipase-and xylanase-producing oleaginous yeast consortium capable of reactive azo dye degradation and detoxification. Bioresour. Technol. 313, 123631.

Ali, S.S., Elsamahy, T., Al-Tohamy, R., Zhu, D., Mahmoud, Y., Koutra, E., Metwally, M.A., Kornaros, M., Sun, J., 2021c. Plastic wastes biodegradation: mechanisms, challenges and future prospects. Sci. Total Environ. 780, 146590.

Ali, S.S., Elsamahy, T., Koutra, E., Kornaros, M., El-Sheekh, M., Abdelkarim, E., Zhu, D., Sun, J., 2021b. Degradation of conventional plastic wastes in the environment. A review on current status of knowledge and future perspectives of disposal. Sci. Total Environ. 771, 144719.

Ali, S.S., Sun, J., Koutra, E., El-Zawawy, N., Elsamahy, T., El-Shetehy, M., 2021d. Construction of a novel cold-adapted oleaginous yeast consortium valued for textile azo dye wastewater processing and biorefinery. Fuel 285, 119050.

Allaoui, M., Berradi, M., Elharfi, A., 2016. Synthesis of a new asymmetric semi permeable membrane and based alloy of two polymers PVC and PSU. Application in the treatment of a colored solution. Mor. J. Chem. 4 (1), 4-1.

Almroth, B.C., Cartine, J., Jönander, C., Karlsson, M., Langlois, J., Lindström, M., Lundin, J., Melander, N., Pesqueda, A., Rahmqvist, I., Renaux, J., 2021. Assessing the effects of textile leachates in fish using multiple testing methods: from gene expression to behavior. Ecotoxicol. Environ. Saf. 207, 111523.

Al-Mutairi, N.Z., 2006. Coagulant toxicity and effectiveness in a slaughterhouse wastewater treatment plant. Ecotoxicol. Environ. Saf. 65 (1), 74–83.

Al-Tohamy, R., Kenawy, E.R., Sun, J., Ali, S.S., 2020a. Performance of a newly isolated salt-tolerant yeast strain *Sterigmatomyces halophilus* SSA-1575 for azo dye decolorization and detoxification. Front. Microbiol. 11, 1163.

Al-Tohamy, R., Sun, J., Fareed, M.F., Kenawy, E.R., Ali, S.S., 2020b. Ecofriendly biodegradation of Reactive Black 5 by newly isolated *Sterigmatomyces halophilus* SSA1575, valued for textile azo dye wastewater processing and detoxification. Sci. Rep. 10 (1), 1–16.

Al-Tohamy, R., Sun, J., Khalil, M.A., Kornaros, M., Ali, S.S., 2021c. Wood-feeding termite gut symbionts as an obscure yet promising source of novel manganese peroxidase-producing oleaginous yeasts intended for azo dye decolorization and biodiesel production. Biotechnol. Biofuels 14, 229.

Amer, O.A., Ali, S.S., Azab, M., El-Shouny, W.A., Sun, J., Mahmoud, Y.A.G., 2022a. Exploring new marine bacterial species, Alcaligenes faecalis Alca F2018 valued for bioconversion of shrimp chitin to chitosan for concomitant biotechnological applications. Int. J. Biol. Macromol. 196, 35–45.

Amin, T., Afrin, M., Haque, Z., Islam, M.R., 2016. Effects of textile dye waste water on reproductive system of mice and their progeny. Int. J. Sci. Eng. Res. 7, 565–570.

An, X., Chen, Y., Chen, G., Feng, L., Zhang, Q., 2020. Integrated metagenomic and metaproteomic analyses reveal potential degradation mechanism of azo dye-Direct Black G by thermophilic microflora. Ecotoxicol. Environ. Saf. 196, 110557.

Ao, S., Zayed, T., 2022. Impact of sewer overflow on public health: a comprehensive scientometric analysis and systematic review. Environ. Res. 203, 111609.

Arshad, H., Imran, M., Ashraf, M., 2020. Toxic effects of Red-S3B dye on soil microbial activities, wheat yield, and their alleviation by pressmud application. Ecotoxicol. Environ. Saf. 204, 111030.

Asses, N., Ayed, L., Hkiri, N., Hamdi, M., 2018. Congo red decolorization and detoxification by *Aspergillus niger*: removal mechanisms and dye degradation pathway. BioMed. Res. Int. 2018.

Atkar, A., Pabba, M., Sekhar, S.C., Sridhar, S., 2021. Current limitations and challenges in the global textile sector. Fundamentals of Natural Fibres and Textiles. Woodhead Publishing, pp. 741–764.

Ayed, L., Mahdhi, A., Cheref, A., Bakhrouf, A., 2011. Decolorization and degradation of azo dye Methyl Red by an isolated *Sphingomonas paucimobilis*: biotoxicity and metabolites characterization. Desalination 274 (1), 272–277.
Badawi, A.K., Zaher, K., 2021. Hybrid treatment system for real textile wastewater remediation based on coagulation/flocculation, adsorption and filtration processes: Performance and economic evaluation. J. Water Process Eng. 40, 101963.
Bafana, A., Krishnamurthi, K., Devi, S.S., Chakrabarti, T., 2008. Biological decolourization of CI Direct Black 38 by *E. gallinarum*. J. Hazard. Mater. 157 (1), 187–193.
Balakrishnan, V.K., Shirin, S., Aman, A.M., de Solla, S.R., Mathieu-Denoncourt, J., Langlois, V.S., 2016. Genotoxic and carcinogenic products arising from reductive transformations of the azo dye, Disperse Yellow 7. Chemosphere 146, 206–215.
Baldev, E., MubarakAli, D., Ilavarasi, A., Pandiaraj, D., Ishack, K.S.S., Thajuddin, N., 2013. Degradation of synthetic dye, Rhodamine B to environmentally non-toxic products using microalgae. Colloids Surf. B 105, 207–214.
Bankole, P.O., Adekunle, A.A., Obidi, O.F., Chandanshive, V.V., Govindwar, S.P., 2018. Biodegradation and detoxification of Scarlet RR dye by a newly isolated filamentous fungus, *Peyronellaea prosopidis*. Sustain. Environ. Res. 28 (5), 214–222.
Basak, B., Jeon, B.H., Kurade, M.B., Saratale, G.D., Bhunia, B., Chatterjee, P.K., Dey, A., 2019. Biodegradation of high concentration phenol using sugarcane bagasse immobilized *Candida tropicalis* PHB5 in a packed-bed column reactor. Ecotoxicol. Environ. Saf. 180, 317–325.
Bayramoglu, G., Kunduzcu, G., Arica, M.Y., 2020. Preparation and characterization of strong cation exchange terpolymer resin as effective adsorbent for removal of disperse dyes. Polym. Eng. Sci. 60 (1), 192–201.
Behera, M., Nayak, J., Banerjee, S., Chakrabortty, S., Tripathy, S.K., 2021. A review on the treatment of textile industry waste effluents towards the development of efficient mitigation strategy: An integrated system design approach. J. Environ. Chem. Eng. 9 (4), 105277.
Bento, R.M., Almeida, M.R., Bharmoria, P., Freire, M.G., Tavares, A.P., 2020. Improvements in the enzymatic degradation of textile dyes using ionic-liquid-based surfactants. Sep. Purif. Technol. 235, 116191.
Berradi, M., Hsissou, R., Khudhair, M., Assouag, M., Cherkaoui, O., El Bachiri, A., El Harfi, A., 2019. Textile finishing dyes and their impact on aquatic environs. Heliyon 5 (11), e02711.
Bhatt, N., Patel, K.C., Keharia, H., Madamwar, D., 2005. Decolorization of diazo-dye reactive blue 172 by *Pseudomonas aeruginosa* NBAR12. J. Basic Microbiol.: Int. J. Biochem., Physiol., Genet., Morphol., Ecol. Microorg. 45 (6), 407–418.
Bhattacharya, S., Gupta, A.B., Gupta, A., Pandey, A., 2018. Introduction to water remediation: importance and methods. Water Remediation. Springer, Singapore, pp. 3–8.
Bilal, M., Asgher, M., Parra-Saldivar, R., Hu, H., Wang, W., Zhang, X., Iqbal, H.M., 2017. Immobilized ligninolytic enzymes: an innovative and environmental responsive technology to tackle dye-based industrial pollutants – a review. Sci. Total Environ. 576, 646–659.
Bilal, M., Rasheed, T., Zhao, Y., Iqbal, H.M., 2019. Agarose-chitosan hydrogel-immobilized horseradish peroxidase with sustainable bio-catalytic and dye degradation properties. Int. J. Biol. Macromol. 124, 742–749.
Brião, G.V., Jahn, S.L., Foletto, E.L., Dotto, G.L., 2018. Highly efficient and reusable mesoporous zeolite synthetized from a biopolymer for cationic dyes adsorption. Colloids Surf. A Physicochem. Eng. Asp. 556, 43–50.
Britos, C.N., Gianolini, J.E., Portillo, H., Trelles, J.A., 2018. Biodegradation of industrial dyes by a solvent, metal and surfactant-stable extracellular bacterial laccase. Biocatal. Agric. Biotechnol. 14, 221–227.
Brüschweiler, B.J., Merlot, C., 2017. Azo dyes in clothing textiles can be cleaved into a series of mutagenic aromatic amines which are not regulated yet. Regul. Toxicol. Pharmacol. 88, 214–226.
Burakov, A.E., Galunin, E.V., Burakova, I.V., Kucherova, A.E., Agarwal, S., Tkachev, A. G., Gupta, V.K., 2018. Adsorption of heavy metals on conventional and nanostructured materials for wastewater treatment purposes: a review. Ecotoxicol. Environ. Saf. 148, 702–712.
Buscio, V., García-Jiménez, M., Vilaseca, M., López-Grimau, V., Crespi, M., Gutiérrez-Bouzán, C., 2016. Reuse of textile dyeing effluents treated with coupled nanofiltration and electrochemical processes. Materials 9 (6), 490.
Cao, G., Wang, R., Ju, Y., Jing, B., Duan, X., Ao, Z., Jiang, J., Li, F., Ho, S.H., 2021. Synchronous removal of emulsions and soluble organic contaminants via a microalgae-based membrane system: performance and mechanisms. Water Res. 206, 117741.
Cardoso, N.F., Lima, E.C., Royer, B., Bach, M.V., Dotto, G.L., Pinto, L.A., Calvete, T., 2012. Comparison of *Spirulina platensis* microalgae and commercial activated carbon as adsorbents for the removal of Reactive Red 120 dye from aqueous effluents. J. Hazard. Mater. 241, 146–153.
Chandanshive, V., Kadam, S., Rane, N., Jeon, B.H., Jadhav, J., Govindwar, S., 2020. In situ textile wastewater treatment in high rate transpiration system furrows planted with aquatic macrophytes and floating phytobeds. Chemosphere 252, 126513.
Chaudhari, A.U., Tapase, S.R., Markad, V.L., Kodam, K.M., 2013. Simultaneous decolorization of reactive Orange M2R dye and reduction of chromate by *Lysinibacillus* sp. KMK-A. J. Hazard. Mater. 262, 580–588.
Chen, G., An, X., Li, H., Lai, F., Yuan, E., Xia, X., Zhang, Q., 2021a. Detoxification of azo dye Direct Black G by thermophilic *Anoxybacillus* sp. PDR2 and its application potential in bioremediation. Ecotoxicol. Environ. Saf. 214, 112084.
Chen, K.C., Wu, J.Y., Liou, D.J., Hwang, S.C.J., 2003. Decolorization of the textile dyes by newly isolated bacterial strains. J. Biotechnol. 101 (1), 57–68.
Chen, Y.G., Huang, J.H., Luo, R., Ge, H.Z., Wołowicz, A., Wawrzkiewicz, M., Gładysz-Płaska, A., Li, B., Yu, Q.X., Kołodyńska, D., Lv, G.Y., 2021b. Impacts of heavy metals and medicinal crops on ecological systems, environmental pollution, cultivation, and production processes in China. Ecotoxicol. Environ. Saf. 219, 112336.
Chequer, F.M.D., Angeli, J.P.F., Ferraz, E.R.A., Tsuboy, M.S., Marcarini, J.C., Mantovani, M.S., de Oliveira, D.P., 2009. The azo dyes Disperse Red 1 and Disperse Orange 1 increase the micronuclei frequencies in human lymphocytes and in HepG2 cells. Mutat. Res. Genet. Toxicol. Environ. Mutagen. 676 (1–2), 83–86.
Cheryan, M., 1998. Ultrafiltration and Microfiltration Handbook. CRC Press.
Chung, K.T., 1983. The significance of azo-reduction in the mutagenesis and carcinogenesis of azo dyes. Mutat. Res. Rev. Genet. Toxicol. 114 (3), 269–281.
Clark, M., 2011. Handbook of Textile and Industrial Dyeing: Principles, Processes and Types of Dyes. Elsevier.
Colin, N., Maceda-Veiga, A., Flor-Arnau, N., Mora, J., Fortuño, P., Vieira, C., Prat, N., Cambra, J., De Sostoa, A., 2016. Ecological impact and recovery of a Mediterranean river after receiving the effluent from a textile dyeing industry. Ecotoxicol. Environ. Saf. 132, 295–303.
Coria-Oriundo, L.L., Battaglini, F., Wirth, S.A., 2021. Efficient decolorization of recalcitrant dyes at neutral/alkaline pH by a new bacterial laccase-mediator system. Ecotoxicol. Environ. Saf. 217, 112237.
Couto, N., Wood, J., Barber, J., 2016. The role of glutathione reductase and related enzymes on cellular redox homoeostasis network. Free Radic. Biol. Med. 95, 27–42.
Darwesh, O.M., Ali, S.S., Matter, I.A., Elsamahy, T., 2021. Nanotextiles waste management: controlling of release and remediation of wastes. Nanosensors and Nanodevices for Smart Multifunctional Textiles. Elsevier, pp. 267–286.
Dasgupta, J., Mondal, D., Chakraborty, S., Sikder, J., Curcio, S., Arafat, H.A., 2015a. Nanofiltration based water reclamation from tannery effluent following coagulation pretreatment. Ecotoxicol. Environ. Saf. 121, 22–30.
Dasgupta, J., Singh, M., Sikder, J., Padarthi, V., Chakraborty, S., Curcio, S., 2015b. Response surface-optimized removal of Reactive Red 120 dye from its aqueous solutions using polyethyleneimine enhanced ultrafiltration. Ecotoxicol. Environ. Saf. 121, 271–278.
Dawkar, V.V., Jadhav, U.U., Ghodake, G.S., Govindwar, S.P., 2009. Effect of inducers on the decolorization and biodegradation of textile azo dye Navy blue 2GL by Bacillus sp. VUS. Biodegradation 20 (6), 777–787.
Dawkar, V.V., Jadhav, U.U., Tamboli, D.P., Govindwar, S.P., 2010. Efficient industrial dye decolorization by *Bacillus* sp. VUS with its enzyme system. Ecotoxicol. Environ. Saf. 73 (7), 1696–1703.
Deivasigamani, C., Das, N., 2011. Biodegradation of Basic Violet 3 by Candida krusei isolated from textile wastewater. Biodegradation 22 (6), 1169–1180.
Deopura, B.L., Padaki, N.V., 2015. Chapter 5: Synthetic textile fibres: polyamide, polyester and aramid fibres. In: Sinclair, R. (Ed.), Textiles and Fashion. Elsevier Science.
Dória, A.R., Pupo, M., Santos, G.D.O.S., da Silva Vilar, D., Torres, N.H., Ferreira, L.F.R., Cavalcanti, E.B., Eguiluz, K.I.B., Salazar-Banda, G.R., 2020. Electrochemical oxidation of indanthrene blue dye in a filter-press flow reactor and toxicity analyses with *Raphidocelis subcapitata* and *Lactuca sativa*. Ecotoxicol. Environ. Saf. 198, 110659.
Dotto, J., Fagundes-Klen, M.R., Veit, M.T., Palácio, S.M., Bergamasco, R., 2019. Performance of different coagulants in the coagulation/flocculation process of textile wastewater. J. Clean. Prod. 208, 656–665.
Dutta, S., Bhattacharjee, J., 2022. A comparative study between physicochemical and biological methods for effective removal of textile dye from wastewater. Development in Wastewater Treatment Research and Processes. Elsevier, pp. 1–21.
Ebency, C.I.L., Rajan, S., Murugesan, A.G., Rajesh, R., Elayarajah, B., 2013. Biodegradation of textile azo dyes and its bioremediation potential using seed germination efficiency. Int. J. Curr. Microbiol. Appl. Sci. 2 (10), 496–505.
Elgarahy, A.M., Elwakeel, K.Z., Mohammad, S.H., Elshoubaky, G.A., 2021. A critical review of biosorption of dyes, heavy metals and metalloids from wastewater as an efficient and green process. Clean. Eng. Technol. 4, 100209.
El-Sheekh, M.M., Abou-El-Souod, G.W., El Asrag, H.A., 2018. Biodegradation of some dyes by the green alga Chlorella vulgaris and The Cyanobacterium *Aphanocapsa elachista*. Egypt. J. Bot. 58 (3), 311–320.
El-Sheekh, M.M., Gharieb, M.M., Abou-El-Souod, G.W., 2009. Biodegradation of dyes by some green algae and cyanobacteria. Int. Biodeterior. Biodegrad. 63 (6), 699–704.
Ertuğrul, S., Bakır, M., Dönmez, G., 2008. Treatment of dye-rich wastewater by an immobilized thermophilic cyanobacterial strain: *Phormidium* sp. Ecol. Eng. 32 (3), 244–248.
Feng, J., Cerniglia, C.E., Chen, H., 2012. Toxicological significance of azo dye metabolism by human intestinal microbiota. Front. Biosci. (Elite Ed.) 4, 568.
Ferraz, E.R., Grando, M.D., Oliveira, D.P., 2011. The azo dye Disperse Orange 1 induces DNA damage and cytotoxic effects but does not cause ecotoxic effects in Daphnia similis and Vibrio fischeri. J. Hazard. Mater. 192 (2), 628–633.
Franca, R.D.G., Vieira, A., Carvalho, G., Oehmen, A., Pinheiro, H.M., Crespo, M.T.B., Lourenco, N.D., 2020. *Oerskovia paurometabola* can efficiently decolorize azo dye Acid Red 14 and remove its recalcitrant metabolite. Ecotoxicol. Environ. Saf. 191, 110007.
Gagné, F., André, C., Cejka, P., Hausler, R., Fournier, M., Blaise, C., 2008. Immunotoxic effects on freshwater mussels of a primary-treated wastewater before and after ozonation: a pilot plant study. Ecotoxicol. Environ. Saf. 69 (3), 366–373.
Garg, S.K., Tripathi, M., 2013. Process parameters for decolorization and biodegradation of orange II (Acid Orange 7) in dye-simulated minimal salt medium and subsequent textile effluent treatment by Bacillus cereus (MTCC 9777) RMLAU1. Environ. Monit. Assess. 185 (11), 8909–8923.
Ghaedi, M., Hajjati, S., Mahmudi, Z., Tyagi, I., Agarwal, S., Maity, A., Gupta, V.K., 2015. Modeling of competitive ultrasonic assisted removal of the dyes–Methylene blue and Safranin-O using Fe3O4 nanoparticles. Chem. Eng. J. 268, 28–37.

Grassi, E., Scodeller, P., Filiel, N., Carballo, R., Levin, L., 2011. Potential of *Trametes trogii* culture fluids and its purified laccase for the decolorization of different types of recalcitrant dyes without the addition of redox mediators. Int. Biodeterior. Biodegrad. 65 (4), 635–643.

Guo, G., Hao, J., Tian, F., Liu, C., Ding, K., Xu, J., Zhou, W., Guan, Z., 2020. Decolorization and detoxification of azo dye by halo-alkaliphilic bacterial consortium: systematic investigations of performance, pathway and metagenome. Ecotoxicol. Environ. Saf. 204, 111073.

Gupta, V., Garg, S., Capalash, N., Gupta, N., Sharma, P., 2015. Production of thermo-alkali-stable laccase and xylanase by co-culturing of *Bacillus* sp. and *B. halodurans* for biobleaching of kraft pulp and deinking of waste paper. Bioprocess Biosyst. Eng. 38 (5), 947–956.

Hamad, H., Bassyouni, D., El-Ashtoukhy, E.S., Amin, N., El-Latif, M.A., 2018. Electrocatalytic degradation and minimization of specific energy consumption of synthetic azo dye from wastewater by anodic oxidation process with an emphasis on enhancing economic efficiency and reaction mechanism. Ecotoxicol. Environ. Saf. 148, 501–512.

Hanger, K., 2003. Industrial dyes: Chemistry, properties and applications, health and safety aspects.

Haq, I., Raj, A., 2018. Biodegradation of Azure-B dye by *Serratia liquefaciens* and its validation by phytotoxicity, genotoxicity and cytotoxicity studies. Chemosphere 196, 58–68.

Hassan, M.M., Carr, C.M., 2018. A critical review on recent advancements of the removal of reactive dyes from dyehouse effluent by ion-exchange adsorbents. Chemosphere 209, 201–219.

Hassanshahi, N., Karimi-Jashni, A., 2018. Comparison of photo-Fenton, O3/H2O2/UV and photocatalytic processes for the treatment of gray water. Ecotoxicol. Environ. Saf. 161, 683–690.

He, H., Xin, X., Qiu, W., Li, D., Liu, Z., Ma, J., 2021. Waste sludge disintegration, methanogenesis and final disposal via various pretreatments: comparison of performance and effectiveness. Environ. Sci. Ecotechnol., 100132

Hocini, I., Benabbas, K., Khellaf, N., Djelal, H., Amrane, A., 2019. Can duckweed be used for the biomonitoring of textile effluents? Eur. J. Environ. Integr. 4 (1), 1–8.

Holkar, C.R., Jadhav, A.J., Pinjari, D.V., Mahamuni, N.M., Pandit, A.B., 2016. A critical review on textile wastewater treatments: possible approaches. J. Environ. Manag. 182, 351–366.

Hossain, M.S., Das, S.C., Islam, J.M., Al Mamun, M.A., Khan, M.A., 2018. Reuse of textile mill ETP sludge in environmental friendly bricks–effect of gamma radiation. Radiat. Phys. Chem. 151, 77–83.

Islam, A., Teo, S.H., Taufiq-Yap, Y.H., Ng, C.H., Vo, D.V.N., Ibrahim, M.L., Hasan, M.M., Khan, M.A.R., Nur, A.S., Awual, M.R., 2021. Step towards the sustainable toxic dyes and heavy metals removal and recycling from aqueous solution-A comprehensive review. Resour. Conserv. Recycl. 175, 105849.

Ismail, G.A., Sakai, H., 2021. Review on effect of different type of dyes on advanced oxidation processes (AOPs) for textile color removal. Chemosphere, 132906.

Jadhav, A.C., Jadhav, N.C., 2021. Treatment of textile wastewater using adsorption and adsorbents. Sustainable Technologies for Textile Wastewater Treatments. Woodhead Publishing, pp. 235–273.

Jadhav, J.P., Parshetti, G.K., Kalme, S.D., Govindwar, S.P., 2007. Decolourization of azo dye methyl red by *Saccharomyces cerevisiae* MTCC 463. Chemosphere 68 (2), 394–400.

Jafari, N., Soudi, M.R., Kasra-Kermanshahi, R., 2014. Biodegradation perspectives of azo dyes by yeasts. Microbiol 83 (5), 484–497.

Jamee, R., Siddique, R., 2019. Biodegradation of synthetic dyes of textile effluent by microorganisms: an environmentally and economically sustainable approach. Eur. J. Microbiol. Immunol. 9 (4), 114–118.

Jiku, M.A.S., Singha, A., Faruquee, M., Rahaman, M.A., Alam, M.A., Ehsanullah, M., 2021. Toxic wastewater status for irrigation usage at Gazipur and Savar industrial vicinity of Bangladesh. Acta Ecol. Sin. 41 (4), 358–364.

Jin, X., Wu, C., Tian, X., Wang, P., Zhou, Y., Zuo, J., 2021. A magnetic-void-porous MnFe2O4/carbon microspheres nano-catalyst for catalytic ozonation: preparation, performance and mechanism. Environ. Sci. Ecotechnol. 7, 100110.

Jun, L.Y., Yon, L.S., Mubarak, N.M., Bing, C.H., Pan, S., Danquah, M.K., Abdullah, E.C., Khalid, M., 2019. An overview of immobilized enzyme technologies for dye and phenolic removal from wastewater. J. Environ. Chem. Eng. 7 (2), 102961.

Kalyani, D.C., Telke, A.A., Dhanve, R.S., Jadhav, J.P., 2009. Ecofriendly biodegradation and detoxification of Reactive Red 2 textile dye by newly isolated *Pseudomonas* sp. SUK1. J. Hazard. Mater. 163 (2–3), 735–742.

Kamali, M., Khodaparast, Z., 2015. Review on recent developments on pulp and paper mill wastewater treatment. Ecotoxicol. Environ. Saf. 114, 326–342.

Katheresan, V., Kansedo, J., Lau, S.Y., 2018. Efficiency of various recent wastewater dye removal methods: a review. J. Environ. Chem. Eng. 6 (4), 4676–4697.

Khalaj, M., Kamali, M., Khodaparast, Z., Jahanshahi, A., 2018. Copper-based nanomaterials for environmental decontamination – an overview on technical and toxicological aspects. Ecotoxicol. Environ. Saf. 148, 813–824.

Khan, M.D., Abdulateif, H., Ismail, I.M., Sabir, S., Khan, M.Z., 2015. Bioelectricity generation and bioremediation of an azo-dye in a microbial fuel cell coupled activated sludge process. PLoS One 10 (10), e0138448.

Khan, R., Bhawana, P., Fulekar, M., 2013. Microbial decolorization and degradationof synthetic dyes: a review. Rev. Environ. Sci. Biotechnol. 12 (1), 75–97.

Khan, S.A., Mehmood, S., Iqbal, A., Hamayun, M., 2020. Industrial polluted soil borne fungi decolorize the recalcitrant azo dyes Synozol red HF–6BN and Synozol black B. Ecotoxicol. Environ. Saf. 206, 111381.

Khataee, A., Vatanpour, V., Ghadim, A.A., 2009. Decolorization of CI Acid Blue9 solution by UV/Nano-TiO2, Fenton, Fenton-like, electro-Fenton and electrocoagulation processes: a comparative study. J. Hazard. Mater. 161 (2–3), 1225–1233.

Khattab, T.A., Rehan, M., Hamouda, T., 2018. Smart textile framework: photochromic and fluorescent cellulosic fabric printed by strontium aluminate pigment. Carbohydr. Polym. 195, 143–152.

Kishor, R., Purchase, D., Saratale, G.D., Saratale, R.G., Ferreira, L.F.R., Bilal, M., Chandra, R., Bharagava, R.N., 2021. Ecotoxicological and health concerns of persistent coloring pollutants of textile industry wastewater and treatment approaches for environmental safety. J. Environ. Chem. Eng. 9, 105012.

Korpi, A., Järnberg, J., Pasanen, A.L., 2009. Microbial volatile organic compounds. Crit. Rev. Toxicol. 39 (2), 139–193.

Kulkarni, A.N., Watharkar, A.D., Rane, N.R., Jeon, B.H., Govindwar, S.P., 2018. Decolorization and detoxification of dye mixture and textile effluent by lichen *Dermatocarpon vellereceum* in fixed bed upflow bioreactor with subsequent oxidative stress study. Ecotoxicol. Environ. Saf. 148, 17–25.

Kumar, C.G., Mongolla, P., Joseph, J., Sarma, V.U.M., 2012. Decolorization and biodegradation of triphenylmethane dye, brilliant green, by *Aspergillus* sp. isolated from Ladakh, India. Process Biochem. 47 (9), 1388–1394.

Lacasse, K., Baumann, W., 2012. Textile Chemicals: Environmental Data and Facts. Springer Science & Business Media.

Lau, Y.Y., Wong, Y.S., Teng, T.T., Morad, N., Rafatullah, M., Ong, S.A., 2014. Coagulation-flocculation of azo dye Acid Orange 7 with green refined laterite soil. Chem. Eng. J. 246, 383–390.

Lellis, B., Fávaro-Polonio, C.Z., Pamphile, J.A., Polonio, J.C., 2019. Effects of textile dyes on health and the environment and bioremediation potential of living organisms. Biotechnol. Res. Innov. 3 (2), 275–290.

Leme, D.M., Primo, F.L., Gobo, G.G., da Costa, C.R.V., Tedesco, A.C., de Oliveira, D.P., 2015. Genotoxicity assessment of reactive and disperse textile dyes using human dermal equivalent (3D cell culture system). J. Toxicol. Environ. Health A 78 (7), 466–480.

Li, F., Katz, L., Hu, Z., 2019a. Adsorption of major nitrogen-containing components in microalgal bio-oil by activated carbon: equilibrium, kinetics, and ideal adsorbed solution theory (IAST) model. ACS Sustain. Chem. Eng. 7 (19), 16529–16538.

Li, F., Katz, L., Qiu, S., 2019b. Adsorptive selectivity and mechanism of three different adsorbents for nitrogenous compounds removal from microalgae bio-oil. Ind. Eng. Chem. Res. 58 (10), 3959–3968.

Li, F., Srivatsa, S.C., Bhattacharya, S., 2019c. A review on catalytic pyrolysis of microalgae to high-quality bio-oil with low oxygeneous and nitrogenous compounds. Renew. Sust. Eng. Rev. 108, 481–497.

Li, F., Zhao, K., Ng, T.S.A., Dai, Y., Wang, C.H., 2022. Sustainable production of bio-oil and carbonaceous materials from biowaste co-pyrolysis. Chem. Eng. J. 427, 131821.

Li, H., Meng, F., Duan, W., Lin, Y., Zheng, Y., 2019d. Biodegradation of phenol in saline or hypersaline environments by bacteria: A review. Ecotoxicol. Environ. Saf. 184, 109658.

Li, H., Xue, S., Cao, Y., Yue, X., Zhang, A., Chen, C., 2020. Photocatalytic reduction of Cr (VI) by WO3@ PVP with elevated conduction band level and improved charge carrier separation property. Environ. Sci. Ecotechnol. 3, 100034.

Li, H., Zhang, R., Tang, L., Zhang, J., Mao, Z., 2014. Evaluation of Bacillus sp. MZS10 for decolorizing Azure B dye and its decolorization mechanism. J. Environ. Sci. 26 (5), 1125–1134.

Li, J., Zheng, B., He, Y., Zhou, Y., Chen, X., Ruan, S., Yang, Y., Dai, C., Tang, L., 2018. Antimony contamination, consequences and removal techniques: a review. Ecotoxicol. Environ. Saf. 156, 125–134.

Li, X., Tang, S., Yuan, D., Tang, J., Zhang, C., Li, N., Rao, Y., 2019e. Improved degradation of anthraquinone dye by electrochemical activation of PDS. Ecotoxicol. Environ. Saf. 177, 77–85.

Liang, C., Wei, D., Zhang, S., Ren, Q., Shi, J., Liu, L., 2021. Removal of antibiotic resistance genes from swine wastewater by membrane filtration treatment. Ecotoxicol. Environ. Saf. 210, 111885.

Liang, J., Ning, X.A., Kong, M., Liu, D., Wang, G., Cai, H., Sun, J., Zhang, Y., Lu, X., Yuan, Y., 2017. Elimination and ecotoxicity evaluation of phthalic acid esters from textile-dyeing wastewater. Environ. Pollut. 231, 115–122.

Lim, S.L., Chu, W.L., Phang, S.M., 2010. Use of *Chlorella vulgaris* for bioremediation of textile wastewater. Bioresour. Technol. 101 (19), 7314–7322.

Liu, J., Chen, J., Zuo, K., Li, H., Peng, F., Ran, Q., Wang, R., Jiang, Z., Song, H., 2021. Chemically induced oxidative stress improved bacterial laccase-mediated degradation and detoxification of the synthetic dyes. Ecotoxicol. Environ. Saf. 226, 112823.

Liu, W., You, Y., Sun, D., Wang, S., Zhu, J., Liu, C., 2018. Decolorization and detoxification of water-insoluble Sudan dye by *Shewanella putrefaciens* CN32 co-cultured with *Bacillus circulans* BWL1061. Ecotoxicol. Environ. Saf. 166, 11–17.

Lobiuc, A., Olaru, S., Hancu, E.I., Costica, N., Fortuna, M.E., Zamfirache, M.M., Constantinescu, G., 2018. Toxicity and removal of Direct Red 28 diazo dye in living polymeric systems. Rev. Chim. 69 (7), 1628–1635.

Madan, S., Shaw, R., Tiwari, S., Tiwari, S.K., 2019. Adsorption dynamics of Congo Reddye removal using ZnO functionalized high silica zeolitic particles. Appl. Surf. Sci. 487, 907–917.

Mahmoud, M.S., 2016. Decolorization of certain reactive dye from aqueous solution using Baker's Yeast (*Saccharomyces cerevisiae*) strain. HBRC J. 12 (1), 88–98.

Mahmoud, M.S., Mostafa, M.K., Mohamed, S.A., Sobhy, N.A., Nasr, M., 2017. Bioremediation of red azo dye from aqueous solutions by *Aspergillus niger* strain isolated from textile wastewater. J. Environ. Chem. Eng. 5 (1), 547–554.

Mahmudabadi, T.Z., Ebrahimi, A.A., Eslami, H., Mokhtari, M., Salmani, M.H., Ghaneian, M.T., Mohamadzadeh, M., Pakdaman, M., 2018. Optimization and economic evaluation of modified coagulation–flocculation process for enhanced treatment of ceramic-tile industry wastewater. AMB Express 8 (1), 1–12.

Malani, R.S., Khanna, S., Moholkar, V.S., 2013. Sonoenzymatic decolourization of an azo dye employing immobilized horse radish peroxidase (HRP): a mechanistic study. J. Hazard. Mater. 256, 90–97.
Mani, S., Bharagava, R.N., 2016. Exposure to crystal violet, its toxic, genotoxic and carcinogenic effects on environment and its degradation and detoxification for environmental safety. Rev. Environ. Contam. Toxicol. 237, 71–104.
Manickam, P., Vijay, D., 2021. Chemical hazards in textiles. Chemical Management in Textiles and Fashion. Woodhead Publishing, pp. 19–52.
Marin, N.M., Pascu, L.F., Demba, A., Nita-Lazar, M., Badea, I.A., Aboul-Enein, H.Y., 2019. Removal of the Acid Orange 10 by ion exchange and microbiological methods. Int. J. Environ. Sci. Technol. 16 (10), 6357–6366.
Martorell, M.M., Pajot, H.F., de Figueroa, L.I., 2017. Biological degradation of Reactive Black 5 dye by yeast *Trichosporon akiyoshidainum*. J. Environ. Chem. Eng. 5 (6), 5987–5993.
Mathuram, M., Meera, R., Vijayaraghavan, G., 2018. Application of locally sourced plants as natural coagulants for dye removal from wastewater: a review. J. Mater. Environ. Sci. 9 (7), 2058–2070.
Matto, M., Husain, Q., 2009. Decolorization of direct dyes by immobilized turnip peroxidase in batch and continuous processes. Ecotoxicol. Environ. Saf. 72 (3), 965–971.
Mishra, S., Maiti, A., 2019. Applicability of enzymes produced from different biotic species for biodegradation of textile dyes. Clean. Technol. Environ. Policy 21 (4), 763–781.
Misra, N., Kumar, V., Goel, N.K., Varshney, L., 2014. Laccase immobilization on radiation synthesized epoxy functionalized polyethersulfone beads and their application for degradation of acid dye. Polymer 55 (23), 6017–6024.
Mohan, S.V., Rao, N.C., Prasad, K.K., Karthikeyan, J., 2002. Treatment of simulated Reactive Yellow 22 (Azo) dye effluents using Spirogyra species. Waste Manag. 22 (6), 575–582.
Mohanty, S.S., Kumar, A., 2021. Enhanced degradation of anthraquinone dyes by microbial monoculture and developed consortium through the production of specific enzymes. Sci. Rep. 11 (1), 1–15.
Mojiri, A., Ohashi, A., Ozaki, N., Kindaichi, T., 2018. Pollutants removal from synthetic wastewater by the combined electrochemical, adsorption and sequencing batch reactor (SBR). Ecotoxicol. Environ. Saf. 161, 137–144.
Montañés, M.T., García-Gabaldón, M., Roca-Pérez, L., Giner-Sanz, J.J., Mora-Gómez, J., Pérez-Herranz, V., 2020. Analysis of norfloxacin ecotoxicity and the relation with its degradation by means of electrochemical oxidation using different anodes. Ecotoxicol. Environ. Saf. 188, 109923.
Mudhoo, A., Ramasamy, D.L., Bhatnagar, A., Usman, M., Sillanpää, M., 2020. An analysis of the versatility and effectiveness of composts for sequestering heavy metal ions, dyes and xenobiotics from soils and aqueous milieus. Ecotoxicol. Environ. Saf. 197, 110587.
Neifar, M., Chouchane, H., Mahjoubi, M., Jaouani, A., Cherif, A., 2016. *Pseudomonas extremorientalis* BU118: a new salt-tolerant laccase-secreting bacterium with biotechnological potential in textile azo dye decolourization. 3 Biotech 6 (1), 107.
Noman, E., Talip, B.A., Al-Gheethi, A., Mohamed, R., Nagao, H., 2020. Decolourisation of dyes in greywater by mycoremediation and mycosorption process of fungi from peatland; primary study. Mater. Today.: Proc. 31, 23–30.
Novotný, Č., Svobodová, K., Erbanová, P., Cajthaml, T., Kasinath, A., Lang, E., Šašek, V., 2004. Ligninolytic fungi in bioremediation: extracellular enzyme production and degradation rate. Soil Biol. Biochem. 36 (10), 1545–1551.
Olisah, C., Adams, J.B., Rubidge, G., 2021. The state of persistent organic pollutants in South African estuaries: A review of environmental exposure and sources. Ecotoxicol. Environ. Saf. 219, 112316.
Olukanni, O.D., Osuntoki, A.A., Kalyani, D.C., Gbenle, G.O., Govindwar, S.P., 2010. Decolorization and biodegradation of Reactive Blue 13 by Proteus mirabilis LAG. J. Hazard. Mater. 184 (1–3), 290–298.
Omar, H.H., 2008. Algal decolorization and degradation of monoazo and diazo dyes. Pak. J. Biol. Sci. 11 (10), 1310–1316.
Oyeniran, D.O., Sogbanmu, T.O., Adesalu, T.A., 2021. Antibiotics, algal evaluations and subacute effects of abattoir wastewater on liver function enzymes, genetic and haematologic biomarkers in the freshwater fish, Clarias gariepinus. Ecotoxicol. Environ. Saf. 212, 111982.
Palas, B., Ersöz, G., Atalay, S., 2019. Bioinspired metal oxide particles as efficient wet air oxidation and photocatalytic oxidation catalysts for the degradation of acetaminophen in aqueous phase. Ecotoxicol. Environ. Saf. 182, 109367.
Pandi, A., Kuppuswami, G.M., Ramudu, K.N., Palanivel, S., 2019. A sustainable approach for degradation of leather dyes by a new fungal laccase. J. Clean. Prod. 211, 590–597.
Parmar, S., Daki, S., Bhattacharya, S., Shrivastav, A., 2022. Microorganism: an ecofriendly tool for waste management and environmental safety. Development in Wastewater Treatment Research and Processes. Elsevier, pp. 175–193.
Parshetti, G.K., Parshetti, S., Kalyani, D.C., Doong, R.A., Govindwar, S.P., 2012. Industrial dye decolorizing lignin peroxidase from Kocuria rosea MTCC 1532. Ann. Microbiol. 62 (1), 217–223.
Patil, K.J., Mahajan, R.T., Lautre, H.K., Hadda, T.B., 2015. Bioprecipitation and biodegradation of fabric dyes by using *Chara* sp. and *Scenedesmus obliquus*. J. Chem. Pharm. Res. 7 (8), 783–791.
Patil, R., Zahid, M., Govindwar, S., Khandare, R., Vyavahare, G., Gurav, R., Desai, N., Pandit, S., Jadhav, J., 2022. Constructed wetland: a promising technology for the treatment of hazardous textile dyes and effluent. Development in Wastewater Treatment Research and Processes. Elsevier, pp. 173–198.
Pearce, C.I., Christie, R., Boothman, C., von Canstein, H., Guthrie, J.T., Lloyd, J.R., 2006. Reactive azo dye reduction by *Shewanella* strain J18 143. Biotechnol. Bioeng. 95 (4), 692–703.
Phugare, S.S., Kalyani, D.C., Patil, A.V., Jadhav, J.P., 2011. Textile dye degradation by bacterial consortium and subsequent toxicological analysis of dye and dye metabolites using cytotoxicity, genotoxicity and oxidative stress studies. J. Hazard. Mater. 186 (1), 713–723.
Piątkowska, M., Jedziniak, P., Olejnik, M., Żmudzki, J., Posyniak, A., 2018. Absence of evidence or evidence of absence? A transfer and depletion study of Sudan I in eggs. Food Chem. 239, 598–602.
Popli, S., Patel, U.D., 2015. Destruction of azo dyes by anaerobic–aerobic sequential biological treatment: a review. Int. J. Environ. Sci. Technol. 12 (1), 405–420.
Qu, Y., Cao, X., Ma, Q., Shi, S., Tan, L., Li, X., Zhou, H., Zhang, X., Zhou, J., 2012. Aerobic decolorization and degradation of Acid Red B by a newly isolated Pichia sp. TCL. J. Hazard Mater. 223, 31–38.
Rahmani, A.R., Mousavi-Tashar, A., Masoumi, Z., Azarian, G., 2019. Integrated advanced oxidation process, sono-Fenton treatment, for mineralization and volume reduction of activated sludge. Ecotoxicol. Environ. Saf. 168, 120–126.
Rápó, E., Posta, K., Csavdári, A., Vincze, B.É., Mara, G., Kovács, G., Haddidi, I., Tonk, S., 2020. Performance Comparison of *Eichhornia crassipes* and *Salvinia natans* on Azo-Dye (Eriochrome Black T) Phytoremediation. Crystals 10 (7), 565.
Rawat, D., Sharma, R.S., Karmakar, S., Arora, L.S., Mishra, V., 2018. Ecotoxic potential of a presumably non-toxic azo dye. Ecotoxicol. Environ. Saf. 148, 528–537.
Riegas-Villalobos, A., Martínez-Morales, F., Tinoco-Valencia, R., Serrano-Carreón, L., Bertrand, B., Trejo-Hernández, M.R., 2020. Efficient removal of azo-dye Orange II by fungal biomass absorption and laccase enzymatic treatment. 3 Biotech 10 (4), 1–10.
Ruscasso, F., Bezus, B., Garmendia, G., Vero, S., Curutchet, G., Cavello, I., Cavalitto, S., 2021. *Debaryomyces hansenii* F39A as biosorbent for textile dye removal. Rev. Argent. Microbiol. 53, 257–265.
Samei, M., Sarrafzadeh, M.H., Faramarzi, M.A., 2019. The impact of morphology and size of zinc oxide nanoparticles on its toxicity to the freshwater microalga, *Raphidocelis subcapitata*. Environ. Sci. Pollut. Res. - Int 26 (3), 2409–2420.
Samsami, S., Mohamadizaniani, M., Sarrafzadeh, M.H., Rene, E.R., Firoozbahr, M., 2020. Recent advances in the treatment of dye-containing wastewater from textile industries: overview and perspectives. Process Saf. Environ. Prot. 143, 138–163.
Saratale, R.G., Gandhi, S.S., Purankar, M.V., Kurade, M.B., Govindwar, S.P., Oh, S.E., Saratale, G.D., 2013. Decolorization and detoxification of sulfonated azo dye CI Remazol Red and textile effluent by isolated *Lysinibacillus* sp. RGS J. Biosci. 115 (6), 658–667.
Saratale, R.G., Saratale, G.D., Chang, J.S., Govindwar, S.P., 2009. Ecofriendly degradation of sulfonated diazo dye CI Reactive Green 19A using *Micrococcus glutamicus* NCIM-2168. Bioresour. Technol. 100 (17), 3897–3905.
Saratale, R.G., Sivapathan, S., Saratale, G.D., Banu, J.R., Kim, D.S., 2019. Hydroxamic acid mediated heterogeneous Fenton-like catalysts for the efficient removal of Acid Red 88, textile wastewater and their phytotoxicity studies. Ecotoxicol. Environ. Saf. 167, 385–395.
Sarvajith, M., Reddy, G.K.K., Nancharaiah, Y.V., 2018. Textile dye biodecolourization and ammonium removal over nitrite in aerobic granular sludge sequencing batch reactors. J. Hazard. Mater. 342, 536–543.
Senthilkumar, S., Perumalsamy, M., Prabhu, H.J., 2014. Decolourization potential of white-rot fungus *Phanerochaete chrysosporium* on synthetic dye bath effluent containing Amido black 10B. J. Saudi Chem. Soc. 18 (6), 845–853.
Sharma, A., Kumar, V., Shahzad, B., Ramakrishnan, M., Singh Sidhu, G.P., Bali, A.S., Handa, N., Kapoor, D., Yadav, P., Khanna, K., Bakshi, P., 2020. Photosynthetic response of plants under different abiotic stresses: a review. J. Plant Growth Regul. 39 (2), 509–531.
Sharma, A., Verma, S., 2017. Treatment of hospital wastewater using electrocoagulation–a review. In: 7th International Conference on Recent Trends in Engineering Science and Management, Genba Sopanrao Moze Collegeof Engineering Balewadi, Pune. 1st- 2ndApril.
Sharma, J., Sharma, S., Soni, V., 2021. Classification and impact of synthetic textile dyes on Aquatic Flora: a review. Reg. Stud. Mar. Sci., 101802
Sharma, K., Sharma, P., Dhiman, S.K., Chadha, P., Saini, H.S., 2022. Biochemical, genotoxic, histological and ultrastructural effects on liver and gills of fresh water fish Channa punctatus exposed to textile industry intermediate 2 ABS. Chemosphere 287, 132103.
Shindhal, T., Rakholiya, P., Varjani, S., Pandey, A., Ngo, H.H., Guo, W., Ng, H.Y., Taherzadeh, M.J., 2021. A critical review on advances in the practices and perspectives for the treatment of dye industry wastewater. Bioengineered 12 (1), 70–87.
Silva, A.C., Silvestre, A.J., Freire, C.S., Vilela, C., 2021. Modification of textiles for functional applications. Fundamentals of Natural Fibres and Textiles. Woodhead Publishing, pp. 303–365.
Singh, H., Raj, S., Kumar, D., Sharma, S., Bhatt, U., Soni, V., 2021. Bioremediation potential of duckweed (Lemna Gibba) in the decolorization of CI Basic Green 4 and chlorophyll a fluorescence analysis. Underst. Plant Perform.
Singha, K., Pandit, P., Maity, S., Sharma, S.R., 2021. Harmful environmental effects for textile chemical dyeing practice. Green Chemistry for Sustainable Textiles. Woodhead Publishing, pp. 153–164.
Sivarajasekar, N., Baskar, R., 2014. Adsorption of basic red 9 on activated waste *Gossypium hirsutum* seeds: process modeling, analysis and optimization using statistical design. J. Ind. Eng. Chem. 20 (5), 2699–2709.
Siwińska-Stefańska, K., Kubiak, A., Piasecki, A., Goscianska, J., Nowaczyk, G., Jurga, S., Jesionowski, T., 2018. TiO_2-ZnO binary oxide systems: Comprehensive characterization and tests of photocatalytic activity. Materials 11 (5), 841.
Soni, V., Keswani, K., Bhatt, U., Kumar, D., Singh, H., 2021. In vitro propagation and analysis of mixotrophic potential to improve survival rate of *Dolichandra unguiscati* under ex vitro conditions. Heliyon 7 (2), e06101.

Sree, K.S., Keresztes, Á., Mueller-Roeber, B., Brandt, R., Eberius, M., Fischer, W., Appenroth, K.J., 2015. Phytotoxicity of cobalt ions on the duckweed *Lemna minor*–Morphology, ion uptake, and starch accumulation. Chemosphere 131, 149–156.
Suryavathi, V., Sharma, S., Sharma, S., Saxena, P., Pandey, S., Grover, R., Kumar, S., Sharma, K.P., 2005. Acute toxicity of textile dye wastewaters (untreated and treated) of Sanganer on male reproductive systems of albino rats and mice. Reprod. Toxicol. 19 (4), 547–556.
Tan, L., He, M., Song, L., Fu, X., Shi, S., 2016. Aerobic decolorization, degradation and detoxification of azo dyes by a newly isolated salt-tolerant yeast Scheffersomyces spartinae TLHS-SF1. Bioresour. Technol. 203, 287–294.
Tan, L., Li, H., Ning, S., Xu, B., 2014. Aerobic decolorization and degradation of azo dyes by suspended growing cells and immobilized cells of a newly isolated yeast Magnusiomyces ingens LH-F1. Bioresour. Technol. 158, 321–328.
Thangaraj, S., Bankole, P.O., Sadasivam, S.K., 2021. Microbial degradation of azo dyes by textile effluent adapted, *Enterobacter hormaechei* under microaerophilic condition. Microbiol. Res. 250, 126805.
Tony, B.D., Goyal, D., Khanna, S., 2009. Decolorization of textile azo dyes by aerobic bacterial consortium. Int. Biodeterior. Biodegrad. 63 (4), 462–469.
Tounsadi, H., Metarfi, Y., Taleb, M., El Rhazi, K., Rais, Z., 2020. Impact of chemical substances used in textile industry on the employee's health: epidemiological study. Ecotoxicol. Environ. Saf. 197, 110594.
Ventura-Camargo, B.D.C., Maltempi, P.P., Marin-Morales, M.A., 2011. The use of the cytogenetic to identify mechanisms of action of an azo dye in *Allium cepa* meristematic cells. J. Environ. Anal. Toxicol. 1 (3), 1–12.
Waghmode, T.R., Kurade, M.B., Govindwar, S.P., 2011. Time dependent degradation of mixture of structurally different azo and non azo dyes by using *Galactomyces geotrichum* MTCC 1360. Int. Biodeterior. Biodegrad. 65 (3), 479–486.
Wan, Z., Jiao, Y., Ouyang, X., Chang, L., Wang, X., 2017. Bifunctional MoS2 coated melamine-formaldehyde sponges for efficient oil–water separation and water-soluble dye removal. Appl. Mater. Today 9, 551–559.
Wang, A.J., Wang, H.C., Cheng, H.Y., Liang, B., Liu, W.Z., Han, J.L., Zhang, B., Wang, S. S., 2020a. Electrochemistry-stimulated environmental bioremediation: development of applicable modular electrode and system scale-up. Environ. Sci. Ecotechnol. 3, 100050.
Wang, X., Xia, J., Ding, S., Zhang, S., Li, M., Shang, Z., Lu, J., Ding, J., 2020b. Removing organic matters from reverse osmosis concentrate using advanced oxidation-biological activated carbon process combined with Fe^{3+}/humus-reducing bacteria. Ecotoxicol. Environ. Saf. 203, 110945.
Will, Y., McDuffie, J.E., Olaharski, A.J., Jeffy, B.D., 2016. Drug Discovery Toxicology: From Target Assessment to Translational Biomarkers. John Wiley & Sons.
Wu, L., Xu, Y., Lv, X., Chang, X., Ma, X., Tian, X., Shi, X., Li, X., Kong, X., 2021. Impacts of an azo food dye tartrazine uptake on intestinal barrier, oxidative stress, inflammatory response and intestinal microbiome in crucian carp (*Carassius auratus*). Ecotoxicol. Environ. Saf. 223, 112551.
Xiang, H., Ren, G., Yang, X., Xu, D., Zhang, Z., Wang, X., 2020. A low-cost solvent-free method to synthesize α-Fe2O3 nanoparticles with applications to degrade methyl orange in photo-fenton system. Ecotoxicol. Environ. Saf. 200, 110744.
Yadav, K.K., Kumar, S., Pham, Q.B., Gupta, N., Rezania, S., Kamyab, H., Yadav, S., Vymazal, J., Kumar, V., Tri, D.Q., Talaiekhozani, A., 2019. Fluoride contamination, health problems and remediation methods in Asian groundwater: a comprehensive review. Ecotoxicol. Environ. Saf. 182, 109362.
Yang, Y., Wei, B., Zhao, Y., Wang, J., 2013. Construction of an integrated enzyme system consisting azoreductase and glucose 1-dehydrogenase for dye removal. Bioresour. Technol. 130, 517–521.
Yu, Z., Wen, X., 2005. Screening and identification of yeasts for decolorizing synthetic dyes in industrial wastewater. Int. Biodeterior. Biodegrad. 56 (2), 109–114.
Zafiu, C., Part, F., Ehmoser, E.K., Kähkönen, M.A., 2021. Investigations on inhibitory effects of nickel and cobalt salts on the decolorization of textile dyes by the white rot fungus *Phanerochaete velutina*. Ecotoxicol. Environ. Saf. 215, 112093.
Zhang, S.J., Yang, M., Yang, Q.X., Zhang, Y., Xin, B.P., Pan, F., 2003. Biosorption of reactive dyes by the mycelium pellets of a new isolate of *Penicillium oxalicum*. Biotechnol. Lett. 25 (17), 1479–1482.
Zhang, X., Li, F., Wang, J., Zhao, H., Yu, X.F., 2021. Strategy for improving the activity and selectivity of CO_2 electroreduction on flexible carbon materials for carbon neutral. Appl. Energy 298, 117196.
Zhao, B., Xiao, W., Shang, Y., Zhu, H., Han, R., 2017. Adsorption of light green anionic dye using cationic surfactant-modified peanut husk in batch mode. Arab. J. Chem. 10, S3595–S3602.
Zhao, H., Cao, P., Lu, L., Li, F., Pang, C.H., Wu, T., 2022. Co-regulation of dispersion, exposure and defect sites on CeO_2 (III) surface for catalytic oxidation of Hg0. J. Hazard. Mater. 424, 126566.
Zheng, X., Fu, D., Cheng, J., Tang, R., Chu, M., Chu, P., Wang, T., Yin, S., 2021. Effects of hypoxic stress and recovery on oxidative stress, apoptosis, and intestinal microorganisms in *Pelteobagrus vachelli*. Aquaculture 543, 736945.
Zhong, J., Yang, B., Gao, F.Z., Xiong, Q., Feng, Y., Li, Y., Zhang, J.N., Ying, G.G., 2021. Performance and mechanism in degradation of typical antibiotics and antibiotic resistance genes by magnetic resin-mediated UV-Fenton process. Ecotoxicol. Environ. Saf. 227, 112908.
Zhu, X., Chen, J., Qiu, K., Kuai, B., 2017. Phytohormone and light regulation of chlorophyll degradation. Front. Plant Sci. 8, 1911.
Zou, H., Ning, X.A., Wang, Y., Zhou, F., 2019. The agricultural use potential of the detoxified textile dyeing sludge by integrated Ultrasound/Fenton-like process: a comparative study. Ecotoxicol. Environ. Saf. 172, 26–32.