IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)
An International Open Access, Peer-reviewed, Refereed Journal

# A Discussion On Physiochemical And Biomediated Removal Approaches Of Dyes From Textile Effluents: A Review

**Vikalp Kumar[1]*, Shehwaz Anwar[2], S. Vijay Prabhu[3]**

[1]Mohan Institute of Nursing and Paramedical Sciences, Bareilly, U. P., India
[2] Mohan Institute of Nursing and Paramedical Sciences, Bareilly, U. P., India
[3]Deapartment of Biotechnology, Microbiology and Bioinformatics, National College, Tiruchirappalli, India

***Abstract:*** When compared to natural colorants, synthetic dyes are more common in the industries due to their lower cost, stability, ease of production, and availability of a wider variety of colors. However, dyes reduce the mobility of oxygen, decrease photosynthesis, and restrict sunlight and affects ecosystem of the biosphere adversely. Therefore, the environment will continue to be concerned about waters that contain dyes. Dyes also have a substantial impact on water quality. In addition, worldwide freshwater shortages are becoming more acute as a result of the fast growing global population, changing climate, and industrial expansion. Hence, water treatment (WT) is currently one of the key study fields due to the depletion of water supplies and excessive environmental pollution. This has made it necessary to upgrade traditional technologies to ones that are safer, more affordable, recyclable, and reusable. Enhancing the effectiveness of its removal from wastewater has been the focus of numerous research projects. The review will discuss the types of textile dyes, their toxicity, and treatment strategies including physical, chemical, and biological remediations.

Index Terms - Dyes, Toxicity, Treatment Approaches, Bioremediation.

## 1. Introduction

Excessive contaminants in water affecting the ecosystem of the biosphere has become an inevitable consequence of instantly growing urbanization, transforming patterns of consumption, rising populations, and social and economic growth, numerous factors which trigger pollution of the environment (Chu and Karr, 2017). Chemical pollutants are frequently identified in aquatic environments as result of human population rise, accelerated industrial development, and urbanization through the years. Many research investigations abound on the pollution of water bodies via chemical pesticides, steroids, and antibiotics.
On the other hand, not much has been discovered regarding synthesized organic dyes that serve as drinking-water pollutants which constitute significant risks to the well-being of humans. The main sources of pollution in natural water from residential and commercial activities include dyes, heavy metals, cyanide, toxic organics, nitrogen, phosphorus, phenols, suspended particles, color, and turbidity. This pollutant load delivers a range of chemical and microbiological contaminants into water sources, increasing treatment costs and posing a substantial challenge to wastewater management. The current study is focused on a brief description of the types of dyes, their toxicity, and strategies for removal of dyes like physical, chemical and biological methods.

## 2. Classification of dyes

On the basis of the color, dyes can be sub classified or subdivided into yellow, orange, red, violet, blue, green, and black .The dyes might be synthetic or natural, depending on where they come from. Plants and other natural materials can be used to make natural dyes. There are many categories for natural colors, including vegetable, mineral, and animal dyes. Man-made synthetic colors can be classified as vat, developed, sulfur, acidic, basic, and direct dyes, . In addition, the color index (CI) and chemical composition and structure have been employed to classify dyes. Anthroquinone, triarylmethane, tri-azo, di-azo, and phthalocyanines are some of the prevalent dye groups. Dyes are further classified into synthetic and natural groups. Acid dyes, basic dyes, sulfur dyes, vat dyes, reactive dyes, solvent dyes, and dispersion dyes are additional groups for the synthetic dyes (Yadav et al., 2023). Animal and plant products offer natural dyes (Fig. 1).

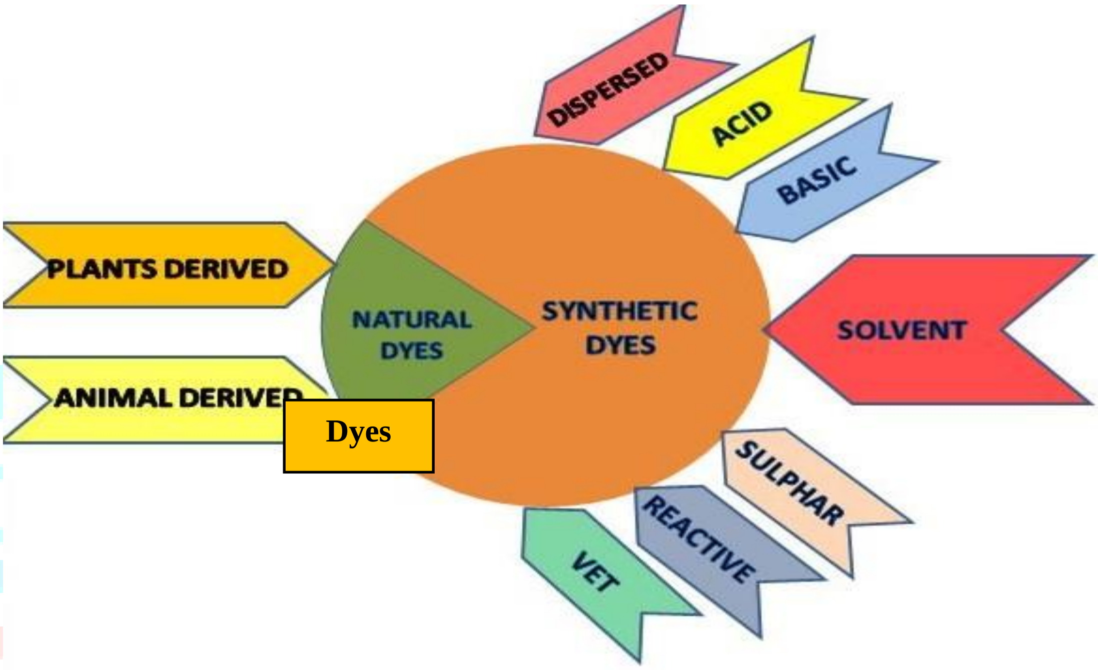



Figure 1.Classification of dyes.

There is an in-depth analysis of the categorization of dyes according to their characteristics and method of application.

### 2.1. Acid dyes

These dyes, containing acidic groups like -SO3H and -COOH, have to be applied to wool, silk, and nylon after an ionic bond develops among the acid group of the dye and the protonated $NH_2$ group of the material being dyed (Kumar et al., 2021). Wash fastness is often low, but light fastness is rather excellent. Higher concentration electrolyte is used to delay dye uptake and create harmonious coloration because the electrical properties of the dye and the material being dyed are opposing. This leads to in a much quicker rate of strike and the absorption of acid dye on such fibers. Acid releases cations on fibers, and heat promotes the substitution of the negative acid ions with anionic color molecules (Ajani et al., 2023). These are naturally occurring anionic colors that dissolve in water. Acid dyes are negative in their soluble state. Acid dyes are made from the sodium or calcium salts of colored organic acids. They are mostly used on silk, wool, and nylon. However, it may be used to make food, cosmetics, paper, leather, and inkjet printing. Anthroquinone, azines, xanthene, nitro, Nitroso, azo (including premetallized), along with Triphenylmethane are just a few of the main functional groups of acidic dyes. The most prevalent chromophore in acidic dyes is the azo group.

### 2.2. Basic (cationic) dyes

Basic dyes are made from salts derived from organic color bases. They are in fact water soluble after the alterations. However, they have the ability to produce colorful cations in solution, so that is the reason they are also known as cationic dyes (Lellis et al., 2019). Synthetic dyes belonging to the basic class function as bases and, on dissolving in water, produce a cationic salt with a color which may interact to the anionic sites located within the substrate's surface. The basic dyes offer textile materials with vibrant colors that have potent tinctorial features. Basic dyes are mostly used to color acrylic fibers that are the result of copolymerization utilizing anionic copolymers. Basic dyes include functional groups including triarylmethane, diazahemicyanine, cyanine, hemi cyanine, thiazine, oxazine, and acridine.Dried flowers, chopped flowers, jute, coir, and other materials are frequently dyed using basic colors. Its purpose was to offer a range of vivid shades of wool and silk. Tannic acid is used as a mordant in basic dyes, also referred to as cationic dyes, which are utilized in cotton, linen, acetate, nylon, polyester, and acrylic materials. Wonderful color can be produced by this kind of dye, however it is not sun, wash, or moisture resistant (Rápó and Tonk, 2021).

**2.3. Disperse dyes**

Disperse dye is a Synthetic dyes utilized for polyester and other similar hydrophobic fabrics. The structure of common dispersion azo dyes is built using a nonionic monoazo functional group and an anthraquinone subunit acting as a chromophore. A visible light-absorbing chromophore (N=N– group) is thought to be the mechanism behind light absorption. An easy technique to change the structure of dyes and affect their optical properties is to synthesise dispersion azo dyes using a diazonium salt and coupling intermediate. Adjusting the functional group of a certain chemical structure allows one to regulate electron delocalization and has a significant impact on the bandgap of the chromophore. It is known that the ensuing electron pushing–pulling balance at the chromophore region is altered by coupling and the diazonium salt precursor side chain chemical group (Cheng et al., 2022). With polar substituents like -NO2 and -CN, disperse dyes are generally tiny, planar, non-ionic molecules. Since the polar groups are necessary for the interaction with the polymer, or for the dye to be retained on the fiber surface, the planar design enables the dye to pass across densely packed polymer chains. Additionally influencing the molecule's UV adsorption, which in turn changes the dye's hue, is the polar group. At high temperatures (120–130 °C) and pressure, the dye is typically administered in an aqueous solution. Thermal agitation opens openings for the dye molecules to penetrate at this temperature range by making the polymer's structure less crystalline and more loose (Tehrani-Bagha et al., 2013).

**2.4. Direct dyes**

These are colored, water-soluble substances that are directly absorbed and have a preference for fiber, like the derivatives of benzidine. Bright colors can be produced by direct dyes, they are frequently affordable and easy to apply. Low wash fastness could have been improved with additional treatment. Direct dyes constitute the biggest portion of packaged dyes offered for domestic usage. Their strong affinity for cellulosic fibers is achieved by mixing anionic dyes with electrolyte, sodium chloride, and sodium sulfate. These colors are molecules that stick to cellulose fibers without help from other materials (Cooper, 1993). They are used for dying cotton, rayon, paper, leather, and nylon.

Without any chemicals, direct dyes have a great affinity for natural textiles. Because there is inadequate hydrogen bonding with the functional groups, materials dyed with direct dyes have moderate washing and light fastness qualities. Conversely, fiber cationic fixing can enhance fastness properties. Because they are carcinogenic, azo and benzidine-based direct dyes are used less frequently in the centralized sector; yet, due to their low cost, cottage businesses still utilize them. Direct colors can stain wool, silk, polyester, and acrylic multi-fibers in addition to having different washing, light, perspiration, and other wet fastness qualities. Unless they have undergone posttreatment, the majority of direct dyes have low wet fastness in medium to full colors; nevertheless, some are stronger (Islam et al., 2022).

These colors are primarily soluble in water and consist mostly of amines and phenols.Whenever employing direct dyes, a little quantity of salt is added to the dying solution, thus the term "salt dyes." They need to be retreated with sodium dichromate and acetic acid in order to be washable. The dye colors are often not particularly bright, with low washing fastness and merely fair light fastness (Freeman and Reifi, 1996).

**2.5. Solvent dyes**

Dye that dissolves in organic solvents is referred to as a solvent dye. In an organic solvent, it is often utilized as a solution (Tehrani-Bagha and Holmberg, 2013). Wax, lubricants, polymers, hydrocarbon-based nonpolar materials, organic solvents, and hydrocarbon fuels may all be colored with solvent dyes. One usage for solvent dyes is in fuel dyes. Their molecules do not ionize and are usually nonpolar or slightly polar. In water, they are insoluble (Marzec, 2014). In solvents, they combine to produce a colloidal solution. Their light fastness varies from good (based on metal complexes) to poor (basic dyes). To create transparent metallic effects on metallized polyester films, such as gold imitation, solvent dyes are utilized. These dyesare used glass coloring, inkjet inks, marking inks, and other purposes. Solvent dyes have special physical properties, one of those that being soluble within an organic solvent. (https://www.primachemicals.com/solvent-dyes-features-applications/).

Solvent dyes are dyes that are soluble in organic solvents and are commonly used as a solvent solution in such solvents. Solvent dyes are not ionized and are not soluble in water. In solution, they are nonpolar. Among the most popular solvents for these colors are alcohols, ethers, ketones, aliphatic and aromatic hydrocarbons, oils, fats, waxes, and chlorinated hydrocarbons. However phthalocyanines and triarylmethane dyes can also be applied, azo and anthroquinone are among the most frequently occurring chemical groups. These varieties of colours are employed for coloring waxes, lubricants, polymers, and other nonpolar hydrocarbon-based products (Cooper, 1993). (https://abbeycolor.com/dyes-and-colorants/solvent-dyes/). .Solvent dyes available in red, yellow, blue, and green colours.

**2.6. Reactive dyes**

Reactive dyes are dyes that react with the fibers to produce covalent bonds which stay permanently bonded to the fibers which are impossible to break down during repeatedly treating these fibers with hot water under a neutral environment. As a result, the dyes integrate into the fiber, providing exceptional color fastness upon washing. After the discovery of it, the reactive dye has continued to be among the most frequently utilized dye for cotton for printing and dyeing in the textile industry as a result of numerous advantages, that includes strong color ranges, intensity, high fastness, affordable price, and ease of application. Reactive dye provides exceptionally high degrees of fastness, especially for wet fastness, although it is applied just as easily as direct dye.They make a covalent bind between the fiber along with the dye in order in order to form a chemical complex. A double bond which had been activated or an haloheterocycle could have the reactive group in them. By chemically bonding with the hydroxyl group that is found in the cellulose fiber, they should are frequently used in alkaline conditions. It is now shown that upon application, the chromophore group is activated and allowed to react with the substrate's surface (Cooper, 1993).

**2.7. Sulfur dyes**

The process of thionation or sulphurization of organic intermediates containing nitro or amino groups produces sulfur dyes, which are synthetic organic dyes. The molecules of sulfur dyes include sulfur bonds. Sulfur dyes are water-insoluble dyes with vibrant colors. Certain sulfur dyes have a partial solubility in water. They are not specifically attracted to cellulose fibers. They must be treated with a reducing agent to change them into soluble forms in order to become substantial. Lightfastness of sulfur dyes is good. They are unsuitable for wool because of the intensely alkaline environment. The production of sulfur dyes is inexpensive and simple. The heat and chemical resistance of sulfur dyes ranges from modest to good. They are not appropriate for use with hypochlorite bleached items because of their low fastness to chlorine. On the other hand, when subjected to a mildly alkaline solution of sodium sulfide or a reducing agent, a leuco compound is produced that exhibits solubility in water and a strong affinity for cellulose materials. They can be used sparingly with polyamide fibers, silk, leather, paper, and for coloring cotton, wood and rayon (Nguyen and Juang, 2013).

**2.8. Vat dyes**

Because of the way they are applied, a family of colors known as vat dyes is recognized. The practice of dying anything inside of a bucket or vat is called "vat dyeing." The first vat dye was indigo, which was formerly exclusively found in plants but is now frequently made synthetically (O'Connell et al., 2008). Normally insoluble in water, they can dissolve in it with the help of a possible reducing agent. Indigo and the anthroquinone derivatives are examples of vat dyes. The dye is applied in a soluble or reduced form by means of fiber impregnation. It oxidizes much more within the fiber, going back to being insoluble. Vat dyes are the fastest dyes for cotton, linen, and rayon.Vat dyes are resistant to oxidizing bleaches, light, acids, and alkali. Pour this solution onto the cloth. When the dye is immersed in an oxidizing solution (bichromate) or is exposed to air, it returns to its insoluble condition as a part of the fiber (Cooper et al., 1993; Yusuf et al., 2017).

### 2.9. Natural dyes

Colorants that come from natural sources are called natural dyes. Up to the middle of the nineteenth century, natural dyes were utilized for all kinds of textile printing and dyeing. Using natural dyes for dyeing is arguably the oldest craft ever discovered. As their first intellectual instrument, people began to use natural dye to create artwork that reflected both themselves and their surroundings. Although natural dyes have been used to color fabrics since ancient times, synthetic dyes took their place in the 19th century with the discovery of mauve colorant. Natural dye is any color, pigment, or material made from renewable, sustainable bioresources—plants, animals, and minerals—that has the least negative effects on the environment. They have been used for coloring textiles, food substrate, natural protein fibers like wool, silk, and cotton, leather, and food components since antiquity. The bulk of naturally occurring dyes come from plants, specifically from the roots, berries, bark, leaves, and wood, as well as from other biological sources like fungi. The introduction of synthetic dyes, notwithstanding their affordability and superior fastness qualities, resulted in a decrease in the usage of natural dyes. However, the resurgence of natural dyes is attributed to global environmental concerns, increased consumer knowledge of the detrimental effects of synthetic dyes, and strict environmental regulations. It's lovely to look at natural hues. Different plants have different expectations for the coloring material that is derived from their roots, stems, leaves, barriers, and flowers (Tamilrasi and Banuchitra, 2021).

## 3. The physical basis of color of dyes

Dye, in contrast to most other organic compounds, has color because it: 1) absorbs light in the visible spectrum (400–700 nm); 2) contains at least one chromophore (a group that bears color); 3) has a conjugated system, meaning that its structure alternates between double and single bonds; and 4) shows electron resonance, which acts as an organic compound's stabilizing force (Ardila-leal et al., 2021; Abrahart, 1977). Various chromophores have different structures and wavelengths associated with them. The color disappears when any one of these components of the molecular structure is absent. Most dyes also contain groups called auxochromes, or color aids, in addition to chromophores. Examples of auxochromes include carboxylic acid, sulfonic acid, amino, and hydroxyl groups. They are mostly employed to affect dye solubility, however they are not the source of color; their presence can change a colorant's color (https://www.ncbi.nlm.nih.gov/books/NBK385442/).

Chromophore is required for a dye. When the quantity of chromophores rises, a dye's hue also increases. The term "chromophore" refers to an alternative conjugated structure with single and double bonds (Ardila-Leal et al., 2021). The dye molecule experiences electron resonance, which stabilizes organic compounds. A molecule absorbs a photon of light, which causes one electron to shift from an anti-bonding orbital to a bonding (non-bonding) orbital. Depending on the kind of electron a molecule has, several types of electronic transitions are possible. The chemical structure of color will be damaged (dye chemistry) if any of these traits are absent. The chromophore experiences $\pi$–$\pi^*$ and n–$\pi^*$ transitions. Most dyes also contain auxochromes, which change the solubility of the color. Examples of these include carboxylic acid groups, amino groups, sulfonic groups, and hydroxyl groups. While n electron transitions are possible for auxochromes, $\pi$–$\pi^*$ transitions are not possible for them (Jiang et al., 2003).

## 4. Azo Dyes

About 65–75% of all textile dye products are made up of azo dyes, which are the most significant and extensive class of industrial dyes (Anwar et al., 2024). As aromatic compounds with N-N groups, they fall under this category. Because azo dyes include the nitro group, which is mutagenic, they are extremely hazardous and, upon breakdown, produce toxic byproducts such o-toluidine and 1,4-phenylenediamine. Azo dyes are regarded as micro contaminants in aquatic ecosystems because of their easy penetration into ambient waterways and large-scale manufacture. It is crucial to regularly check the presence of azo dyes in aquatic systems due to their naturally occurring mutagenesis properties. The fact that dyes containing water block sunlight and hinder photosynthesis is clear.Moreover, colorants disrupt gas solubility, which has an impact on aquatic plant and animal development (Benkhaya et al., 2020).

## 5. The toxicity of dyes

over 35 million individuals have jobs internationally in the textile industry, that has been estimated to have a value worth one trillion United States dollars as well as generates approximately seven percent of total exports overall the international economy (https://www.census.gov/foreign-trade/Press-Release/current_press_release/ft900.pdf). As a result of the pollutants that that this industry provides, its actions have an adverse impact on the ecosystem along with the overall wellness of the public. Pollution of water through the production of dyes is among the most observable & dangerous kind of pollutants brought on by the production of textiles. In addition to being visually unsettling, textile effluents also have high salinity, chemical oxygen demand, and ecotoxicity (Parvin et al., 2020). Because they are becoming more and more common in surface water, they may also have negative consequences on the health of people, wildlife, and aquatic ecosystems as a whole.The majority of synthetic dyes have both short-term and long-term harmful impacts on aquatic and human health. Reactive dyes are well-known for their ability to induce health problems in workers who handle them, including dermatitis, occupational asthma, rhinitis, and other allergic responses (Ardila-Leal et al., 2021). Additionally, dyes have been shown to be mutagenic and carcinogenic, which can have long-term impacts on workers such as liver, kidney, and bladder cancer. Both people and animals are susceptible to cancer, neurological damage, along with mutations in DNA. (https://medlineplus.gov/ency/article/002784.htm#:~:text=Poisoning%20from%20dye%20containing%20an,can%20lead%20to%20tissue%20death).

Copper, nickel, and chromium are among the heavy metals found in metallic complexes dyes, which have been widely used due to their adaptability. Metals such as mercury can enter aquatic ecosystems by means of the gills of fish and then become consumed by people through food chain.Because dye effluents are resistant in aerobic conditions, current treatment procedures are insufficient to properly treat them (Al-Tohamy et al., 2022). As a result, these compounds can persist in soil and produce biological accumulation, which may cause consequences for organisms further up the food chains. Therefore, the dyeing industry is unable to utilize currently available wastewater treatment procedures, so we need to implement innovative safer and more efficient methods for wastewater treatment including bioremediation processes or adsorption of biochar in order to avoid surface waters from becoming polluted by such mutagenic as well as cancer-causing toxic substances (Lellis et al., 2019). The toxic effects of dyes can have detrimental consequences on both the environment and biological organisms. Regulations in the United States state that several dyes and pigments are carcinogenic. These include colors including CI Direct Black 38, CI Acid Red 114, CI Direct Blue 15, and CI Direct Blue 218 which contains benzidine and benzidine congener dyes (Desore et al., 2018).

Azo dyes are chemically constituted having a number of nitrogen-nitrogen double bonds (-N=N-), which are referred to as azo groups. When the azo dyes are consumed orally, enzymes known as azoreductases in the cells of the liver or gut micro flora metabolize the compounds into aromatic amines. Further the transformation of aromatic amines into genetically toxic compounds occurs through human microsomal enzymes (Zafar et al., 2022).

It has been proposed that dye toxicity is influenced by electron transport, reactive oxygen species, and oxidative stress (Kovacic and Somanathan, 2014). The imbalance between the generation and removal of reactive oxygen species is the cause of oxidative stress (Rahmani et al., 2023; Rahmani et al., 2022; Anwar and Younus, 2018). Reactive oxygen species are highly reactive chemical species that are created continuously by the body as a byproduct of cell metabolism and contain oxygen (Anwar et al., 2023; Anwar et al., 2022). Many times, antioxidants stop or lessen toxicity (Kovacic and Somanathan, 2014). Synthetic coloring agents, such as dyes, are widely utilized in a variety of industries, including the infrastructure, grocery, paper printing, rubber, and cosmetic products sectors (Mohan and Sharma, 2022).

Azole dyes are generally directly carcinogenic or mutagenic, with an exception of ones which contain free amino groups. Under reductive circumstances, the azo groups might separate to form two aromatic amines. Once azo linkages are broken, toxic amines are discharged into the surrounding water. For both people and aquatic life, these intermediary products have grave deleterious effects. The brain, liver, kidneys, central nervous system, and reproductive system are among the vital human organs harmed by these intermediates (Feng et al., 2012). However, they may reduce the activity of photosynthesis by decreasing the absorption of light. From the disposal location towards the receiving water, a dye's toxicity consequently flows. Therefore, investigators are being asked to discover methods that will remove these harmful chemicals in advanced countries throughout the world (Alsukaibi,et al., 2022). Azo dyes are a type of synthetic dyes that are frequently employed as a vital component in the textile production sector. It has already been demonstrated that azo dyes are hepatotoxic (Hussain et al., 2022). According to Almatroodi et al. (2020) and Yahia and Anwar (2021) the liver is a vital organ of the body. Thus, azo dye hepatotoxicity can pose a serious hazard to life. Considering the intricate molecular composition of the dyes, traditional physical, chemical, and biological techniques for wastewater eliminationis too challenging .In order to determine how they could help deal with the discoloration difficulty, certain novel innovations have been investigated.

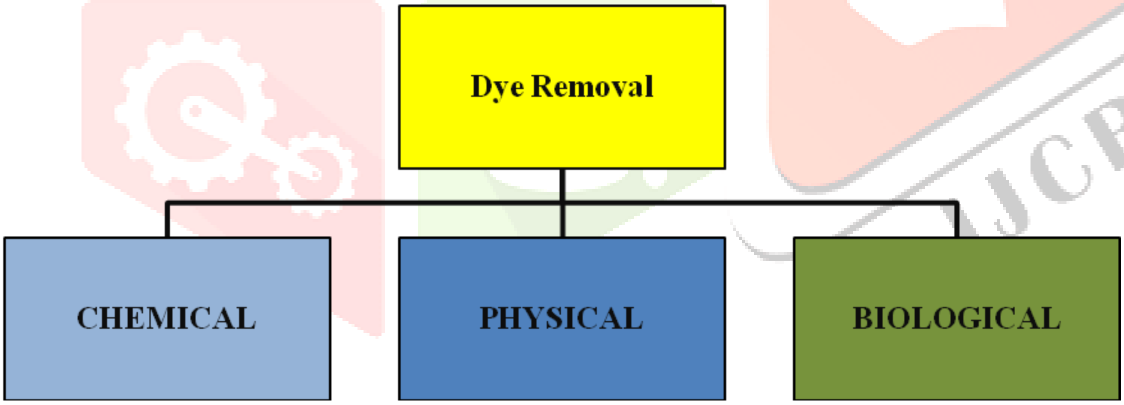
## 6. Pollution from the dye-containing effluents

Investigations have proven the high carcinogenic and toxic effects of textile dyes. The colorful effluent also has a detrimental aesthetic effect on the wastewater since it is visible to the human eye even at concentrations below 1 ppm. In addition, the solubility of gases and the purity of water are affected by the absorption and reflection of sunlight by colored wastewater (Jamee and Siddique, 2019). Effluents produced by both residential and business operations include a number of pollutants, including color, turbidity, nitrogen, phosphorus, phenols, metals such as mercury, cyanide, toxic organic compounds, suspended material, and nitrogen. Due to the fact that it exposes water to a variety of chemical and microbiological pollutants and increases treatment costs, this pollution load offers a serious challenge to wastewater management.Investigations have demonstrated that higher plants and algae have considerable amounts of heavy metal ions that come from wastewater from textile factories (Alsukaibi et al., 2022).

Additionally, dyes along with the biodegradable forms of them consist of toxins, cancer, and mutagenic properties. It has been demonstrated that this increased accessibility of a smaller scale industries has resulted for the introduction of distributed methods of therapy for specific industry sectors. These dangerous chemicals ultimately end up in the environment since proper treatment is expensive, making up around 40% of all industrial effluent (Ashraf et al., 2021). The development of sustainable innovations which can decrease the use of freshwater and wastewater production are pushed by the urgent requirement for protecting the natural environment in this age of industrialization.Concern among the public increases as well as legal challenges are kept to a minimum whenever large quantities of chemical dyes are discharged into the natural environment (Castillo-Suárez et al., 2023).

## 7. Methods of Removal of Dyes

The environment and public health are at risk due to the discharge of this industrial waste dye into waterways. The removal of contaminants from sewage or environmental waters can be accomplished using a multitude of techniques. The majority of them fall into the categories of physical, chemical, and biological purification procedures (Fig.2) (Kaykhaii et al., 2018). Compared to the often employed chemicals and physicochemical approaches, biological dye removal from textile and dyestuff manufacturing industry effluents offers certain clear advantages.




### 7.1. Physical Methods for the Removal of Dyes

Several cheap resources, such as waste from agriculture material, naturally occurring materials, along with industrial scrap material, are being performed for the elimination of dyes. These include the use of activated Carbon, Using Sludge, Using Red Mud, Fly Ash Fly, Using Clay, etc. A variety of physical methods have been demonstrated to be both easy and cheap for the elimination of dyes from textile waste. The adsorption is another most popular practice in the dye elimination procedure. The following physico-chemical procedure has been demonstrated to be most simple and economical for the elimination of dyes from textile waste materials (Kaykhaii et al., 2018).

### 7.2. Chemical Methods for the Removal of Dyes

To remove colors from the effluents of the textile industry, a variety of chemical techniques are utilized, such as advanced oxidation using Fenton's reagent, hydrogen peroxide, ozonization, solvent extraction method, and electrocoagulation (Adane et al., 2021).

### 7.2.1. Advanced Oxidation

The advanced oxidation technique is a conventional approach utilized in the de-colorization process. It is predicated on the process of the hydroxyl radical creation (as oxidizing agents), which induces the production of organic peroxide radicals upon assault against the chromogenic groups, which subsequently convert them into $CO_2$, $H_2O$, and inorganic salts. It involves several techniques, including the ones that have been covered here, including ozonization, the use of hydrogen peroxide, and Fenton's process (Antoniadis et al., 2010).

### 7.2.2. Using Hydrogen Peroxide

Hydrogen peroxide ($H_2O_2$) is a naturally occurring chemical compound composed of two hydrogen atoms and two oxygen atoms that can be found in rainwater and some natural springs. It can also be produced synthetically and used for several purposes, including disinfecting surfaces and eliminating odors in well water. (https://www.cleanwaterstore.com/blog/eliminate-well-water-odors-four-reasons-why-hydrogen-peroxide-well-water-treatment-is-best/#:~:text=When%20injected%20into%20water%2C%20hydrogen,water%2C%20only%20oxygen%20and%20water). Research demonstrated that the elimination efficiency for the dyes methylene blue and rhodamine-B were 86% and 99%, respectively, as reported (Khatee et al., 2009).

### 7.2.3. Using Fenton's Reagent

The Fenton method involves reacting wastewater with hydrogen peroxide and iron catalyst. The creation of perhydroxyl (HO2) and free hydroxyl (OH), which are highly oxidative radicals, during this reaction is essential to the process's success since these radicals react quickly with wastewater. Many benefits of the Fenton process include its simplicity in processing, its ability to function at high temperatures, its capacity to increase the concentration of oxygen in water, and its oxidation and coagulation characteristics. The elimination of different colors has been studied using Fenton's reagent, one of the sophisticated oxidation processes. Utilizing $Fe^{+2}$ as a catalyst, this process produces hydroxyl radicals from $H_2O_2$ which are then used to oxidative degrade organic contaminants (Babuponnusami and Muthukumar, 2014).

### 7.2.4 Ozonisation Process

Greater than $Cl_2$ and $H_2O_2$, Ozone is considered the most potent oxidant. Chlorinated hydrocarbons, phenols, and some other hydrocarbons have been seen to be effectively oxidized by ozone. While findings for rhodamine-B basic dyes are found to be mild and for dispersion dyes to be poor, other investigations have shown that reactive dyes exhibit a significant degree of degradation with $O_3$ (Rekhate and Srivastava, 2020).

### 7.2.5 Electro-Coagulation Process

Without the need for additional chemicals, wastewater can be treated electrochemically by removing small particles through a process called electrocoagulation (EC). It has been shown that a straightforward, dependable electrocoagulation process is a useful instrument for dye removal with potentially improved outcomes (Ebba et al., 2022).

### 7.3. Biological Methods for the Removal of Dyes

When decolorizing dyes, traditional biological methods are either utilized alone or in conjunction with chemical and physical methods. Advanced biological techniques, however, are prioritized since they are more economical, more efficient, and produce less secondary sludge. Different types of organic and inorganic contaminants can be effectively bioremediated using microbial techniques. Several studies have shown that bacterial treatment is an effective method for decolorizing dyes. The treatment process using the biological technique Dissolved organic matter may be eliminated from textile effluents using the biological technique. Many microorganisms, including bacteria, fungus, and algae, are involved in the bio-decolorization processes. It was discovered that these bio-sorbents, which come from the breeding of mushrooms, peat, chitosan, and plant debris, are inexpensive and may be obtained as live or dead microorganisms (Tripathi et al., 2023).

### 7.3.1. Bacteria Based Methods

Many microorganisms, including fungus, bacteria, and algae, are involved in the bio-decolorization process. These microorganisms, which are available in both dead and live forms, are discovered to be inexpensive bio sorbents derived from breeding of mushrooms, peat, chitosan and plant waste. Because bacteria grow more quickly than fungi, dyes can be decolored by them more quickly. For the removal of various azo dyes from textile dye effluents, bacterial cells offer a promising and affordable solution. Comparing bacteria to filamentous fungi, there are a number of benefits: they can grow more quickly, have a longer hydraulic retention period, and may be more effective in treating highly concentrated organic effluent (Kalyani et al., 2009; Ali, 2010). High elimination efficiency was achieved by a variety of bacterial species, including *Pseudomonas putida*, *Pseudomonas aeruginosa*, *Aeromonas hydrophila*, *P. plecoglossicida*, *Lysinibacillus fusiformis*, *P. monteilli*, *Comamonas testosterone*, and *Corynebacterium glutamicum* (Carias et al., 2008; Nigam et al., 1996; Banat et al., 1996). For the Removal of Rhodamine-B Dye, *Lysinibacillus fusiformis*, *Pseudomonas putida*, *Aeromonas hydrophila*, *P. plecoglossicida*, and *P. monteilli* are a few examples of the bacteria that have been utilized to achieve extraction efficiencies of 55%, 50%, 55%, 46%, 56%, and 56%, respectively (Fulekar et al., 2013).

### 7.3.2. Fungus Based Methods

The breakdown of synthetic colors, or occasionally the completion of it, could be best accomplished by fungal species such as *Fusarium solani*, *Aspergillus flavus*, *Alternaria solani*, *Pencillium expansm*, *Fomitopsis carriea*, *Rhizopus oryzae*, and *Aspergillus niger*. The strong extracellular and intracellular enzyme system, which includes lignin peroxidase, manganese peroxidase, and laccase, as well as the robust morphology and diverse metabolic activity, are responsible for these degrading features. Fungal species' mycelia have an advantage over unicellular organisms in that they use enzymes to solubilize insoluble substances (Akansha et al., 2023). By adhering a dye to hyphae, fungi start the process, which is then carried out by enzymes breaking down chemical bonds (Prabha et al., 2017). Nevertheless, there are certain intrinsic disadvantages to using fungi to remove dye from textile effluent, including their lengthy life cycle and requirement for nitrogen-limiting conditions (Parmar et al., 2018). Pha. chrysosporium and Dichomitus squalens were found to decolorize Congo red, according to Gill et al. (Gill et al., 2002). Maximum decolorization of Reactive Orange 16 by the fungus strain Irpex lacteus has been reported to reach 80% by Svobodová et al. (Svobodová et al., 2007).
The ability of Ganoderma lucidum, Pycnoporus cinnamonabarinus, Pleurotus pulmonarius, Stereum ostrea, and Trametes suaveolens to decolorize Congo red (100 mg/L) has been reported by Jayasinghe et al. (Jaysinghe et al., 2008).

### 7.3.3. Algae Based Methods

Algae are a valuable resource for phycoremediation because of their rapid development, high removal capabilities, and adaptability to a variety of settings, including bioreactors and wastewater ponds. Algal species like Sargassum sp., Ulva sp., Spirogyra sp., and Spirullina can also improve nutrient assimilation and restore ecosystem equilibrium when used in phycoremediation. Among the classes of microorganisms are algae, which have also been tested as a bio sorbent for color removal. It has been investigated if some algae species may bio decolorize colors. Utilizing algae's ability to remove or degrade pollutants, phycoremediation is a unique kind of bioremediation. Algae possess unique metabolic abilities and have the ability to remove pollutants through a variety of processes, including biosorption, bioaccumulation, and degradation. Research has demonstrated the effectiveness of phycoremediation in the treatment of wastewater, removal of nutrients, sequestration of carbon, and remediation of pollutants such as organic compounds, heavy metals, and excess nitrogen and phosphorus. In addition, some algal species have demonstrated the capacity to accumulate dyes through the process of biosorption (Nair et al., 2023).

### 7.3.4. Yeast based dye removal

The chemical characteristics of each reaction molecule determine how microorganism (yeast, bacteria, fungi, and/or algae) interacts with dyes. Compared to bacteria and filamentous fungi, yeasts have a number of advantages. Yeasts' unicellular structure and rapid development make them an ideal raw biosorbent material for eliminating reactive dye. Yeast cells are an easily accessible source of biomass with the potential to be used in the bio-remediation of wastes because they can be grown into low-cost growth media (Mahmoud, 2016). One of the most common forms of biomass that can be used for textile dye bioremediation is *Saccharomyces cerevisiae* (Aksu, 2003). S. cerevisiae is recognized to be affordable, safe, easy to cultivate, widely accessible, and to yield large amounts of biomass (Farah et al., 2007). Because of their fast growth rate and unicellular nature, yeasts make excellent raw biosorbent materials for the removal of reactive dye. Yeast cells are an easily accessible source of biomass with the potential to be used in the bio-remediation of pollutants since they are affordable to produce in growth conditions (Mahmoud, 2016).

#### 7.3.5. Plant based removal

An environmentally benign in-situ technique for eliminating contaminants is phytoremediation. The most popular method for reducing and getting rid of heavy metals and textile dyes from the environment is using plants (Yan et al., 2020). Leaf-based materials, whether in their raw or activated state, have drawn the most attention among the evaluated adsorbents. This is mostly due to their low cost, wide availability practically everywhere in the globe, ease of production, and oftentimes lack of secondary uses. Furthermore, in keeping with the circular economy tenets, the amount of trash generated can be greatly decreased by using leaf-based materials as sorbent materials for the sorption of colors from aquatic effluents. However, a range of inorganic and organic substances, including cellulose, hemicellulose, pectins, lignin, and others, are present in the products made from the leaves of various plants (Prol et al., 2017). Various functional groups, including hydroxyl, carboxyl, carbonyl, amino, and nitro, are included in the constitution of these substances (Ngo et al., 2015). Researchers have worked hard to produce a low-cost alternative to traditional remediation technologies that can be just as effective as the adsorptive removal of organic dyes, an area of research that is constantly expanding. Using leaf-based adsorbents, good removal percentages and adsorption capacities were found in most tests (Bulgariu et al., 2019).

## 8. Conclusion

The market is filled with a variety of dyes. Synthetic dyes can be easily acquired and are cheap to purchase. They are now deemed necessary for modern civilization due to their effective coloring ability. Aquatic life, human health, and the ecology as a whole are all negatively impacted by synthetic coloring. The treatment of textile waste water has been compared using a variety of physiochemical techniques, such as adsorption, electrocoagulation, advanced oxidation, solvent extraction, and biological techniques like bacterial and fungal. The removal of dyes with an adsorption approach has been proven to be more successful and have greater removal efficiency when low-cost or free adsorbent materials, such as naturally occurring, agricultural, and industrial waste materials, are used.The textile industry would benefit financially from using wastewater released leftovers like adsorption agents. Metropolitan areas are suffering from an unsafe water supply problem. as water recycling is essential to the livelihood of the local community. Due to their low cost, ease of use, and greater effectiveness—all without any negative effects biological techniques are more dependable when it comes to eliminating colors from textile effluents.Our recommendation is to use biological ways to remove colors from textile and paper industries, as evidenced by current research.The discipline should concentrate on more sophisticated approaches in the future, such as enzymatic methods and methods based on nanotechnology.

**Funding:** None.

**Conflict of interest:** The authors declare no conflict of interest.

**Author contributions-** Concept: Shehwaz Anwar, Vikalp Kumar; Writing and Editing- Shehwaz Anwar, Vikalp Kumar, S. Vijaya Prabhu.

**Acknowledgement:** The authors are very thankful to Mr. Maurya, Chairman, Mohan Group of Nursing, Pharmacy and Paramedical Sciences for their support and providing facilities for laboratory working and internet facility.

**References**


1) Cheng YW, Benas JS, Liang FC, Lin SM, Huang YH, Chen WW, Chen YT, Lee CH, Yu YY, Kuo CC. Red Disperse Azo Dye Side Chains Influence on Polyethylene Terephthalate Dyeing Performances in Supercritical Carbon Dioxide Media. Polymers (Basel). 2022 Dec 15;14(24):5487. doi: 10.3390/polym14245487. PMID: 36559854; PMCID: PMC9782905.
2) Tehrani-Bagha, Ali Reza, and Krister Holmberg. 2013. "Solubilization of Hydrophobic Dyes in Surfactant Solutions" *Materials* 6, no. 2: 580-608. https://doi.org/10.3390/ma6020580
3) P. Cooper. Removing colour from dyehouse wastewaters – a critical review of tech- nology available. Journal of the Society of Dyers and Colourists 1993; 109: 97–100.
4) Islam MT, Islam T, Islam T, Repon MR. Synthetic Dyes for Textile Colouration: Process, Factors and Environmental Impact. Textile & Leather Review. 2022; 5:327-373.
5) Freeman, H.S. Reife. Environmental Chemistry of Dyes and Pigments, Wiley, New York, 1996.
6) Tehrani-Bagha AR, Holmberg K. Solubilization of Hydrophobic Dyes in Surfactant Solutions. Materials (Basel). 2013 Feb 21;6(2):580-608. doi: 10.3390/ma6020580. PMID: 28809328; PMCID: PMC5452102.
7) Anna Marzec. The effect of dyes, pigments and ionic liquids on the properties of elastomer composites. Polymers. Université Claude Bernard - Lyon I; Uniwersytet lódzki, 2014. English. ffNNT : 2014LYO10285ff. fftel-01166530v2f.
8) https://www.primachemicals.com/solvent-dyes-features-applications/.
9) https://abbeycolor.com/dyes-and-colorants/solvent-dyes/.
10) https://www.alfa-chemistry.com/products/sulfur-dyes-113.htm/
11) Nguyen TA, Juang RS. Treatment of waters and wastewaters containing sulfur dyes: A review. Chemical engineering journal. 2013 Mar 1;219:109-17.
12) Yusuf M, Shabbir M, Mohammad F. Natural Colorants: Historical, Processing and Sustainable Prospects. Nat Prod Bioprospect. 2017 Feb;7(1):123-145. doi: 10.1007/s13659-017-0119-9. Epub 2017 Jan 16. PMID: 28093670; PMCID: PMC5315675.
13) D.W. O’Connell, C. Birkinshaw, T.F. O’Dwyer. Heavy metal adsorbents prepared from the modification of cellulose: a review. Bioresource Technology 2008; 99: 6709– 6724.
14) Abrahart EN(1977). *Dyes and their Intermediates*. New York: Chemical Publishing, pp. 1–12.
15) https://www.ncbi.nlm.nih.gov/books/NBK385442/.
16) Jiang LP, Wang Y, Li RQ, Li N, Zhou WY. [Study on the auxochrome of the electronic spectrum of organic compounds and its effect mechanism (I)]. Guang Pu Xue Yu Guang Pu Fen Xi. 2003 Feb;23(1):17-21. Chinese. PMID: 12939957.
17) Benkhaya S, M'rabet S, El Harfi A. Classifications, properties, recent synthesis and applications of azo dyes. Heliyon. 2020 Jan 31;6(1):e03271. doi: 10.1016/j.heliyon.2020.e03271. PMID: 32042981; PMCID: PMC7002841.
18) Anwar S, Kumar V, Yahia EA, Prabhu SV. Optimization of Various Factors Affecting Pseudomonasaeruginosa Mediated Removal of Azo Dye. International Journal of Creative Research Thoughts (IJCRT).2024a, 12(1), 538-549.
19) Parvin F, Islam S, Akm SI, Urmy Z, Ahmed S. A study on the solutions of environment pollutions and worker’s health problems caused by textile manufacturing operations. Biomed. J. Sci. Tech. Res. 2020;28:21831-44.
20) Ardila-Leal LD, Poutou-Piñales RA, Pedroza-Rodríguez AM, Quevedo-Hidalgo BE. A Brief History of Colour, the Environmental Impact of Synthetic Dyes and Removal by Using Laccases. Molecules. 2021 Jun 22;26(13):3813. doi: 10.3390/molecules26133813. PMID: 34206669; PMCID: PMC8270347.
21) https://medlineplus.gov/ency/article/002784.htm#:~:text=Poisoning%20from%20dye%20containing%20an,can%20lead%20to%20tissue%20death.
22) Al-Tohamy R, Ali SS, Li F, Okasha KM, Mahmoud YA, Elsamahy T, Jiao H, Fu Y, Sun J. A critical review on the treatment of dye-containing wastewater: Ecotoxicological and health concerns of textile dyes and possible remediation approaches for environmental safety. Ecotoxicol Environ Saf. 2022 Feb;231:113160. doi: 10.1016/j.ecoenv.2021.113160. Epub 2022 Jan 10. PMID: 35026583.
23) Lellis B, Fávaro-Polonio CZ, Pamphile JA, Polonio JC. Effects of textile dyes on health and the environment and bioremediation potential of living organisms. Biotechnology Research and Innovation. 2019 Jul 1;3(2):275-90.

24) Desore, A.; Narula, S.A. An overview on corporate response towards sustainability issues in textile industry. Environ. Dev. Sustain. 2018, 20, 1439–1459, doi: 10.1007/s10668-017-9949-1.
25) Zafar S, Bukhari DA, Rehman A. Azo dyes degradation by microorganisms-An efficient and sustainable approach. Saudi Journal of Biological Sciences. 2022 Sep 6:103437.
26) Feng J, Cerniglia CE, Chen H. Toxicological significance of azo dye metabolism by human intestinal microbiota. Front Biosci (Elite Ed). 2012 Jan 1;4(2):568-86. doi: 10.2741/e400. PMID: 22201895; PMCID: PMC5870118.
27) Alsukaibi, Abdulmohsen K. D. 2022. "Various Approaches for the Detoxification of Toxic Dyes in Wastewater" *Processes* 10, no. 10: 1968. https://doi.org/10.3390/pr10101968
28) Jamee R, Siddique R. Biodegradation of Synthetic Dyes of Textile Effluent by Microorganisms: An Environmentally and Economically Sustainable Approach. Eur J Microbiol Immunol (Bp). 2019 Oct 3;9(4):114-118. doi: 10.1556/1886.2019.00018. PMID: 31934362; PMCID: PMC6945995.
29) Ashraf RS, Abid Z, Shahid M, Rehman ZU, Muhammad G, Altaf M, Raza MA. Methods for the treatment of wastewaters containing dyes and pigments. Water pollution and remediation: Organic pollutants. 2021:597-661.
30) Castillo-Suárez LA, Sierra-Sánchez AG, Linares-Hernández I, Martínez-Miranda V, Teutli-Sequeira EA. A critical review of textile industry wastewater: green technologies for the removal of indigo dyes. Int J Environ Sci Technol (Tehran). 2023 Mar 27:1-38. doi: 10.1007/s13762-023-04810-2. Epub ahead of print. PMID: 37360556; PMCID: PMC10041522.
31) De Gisi S, Lofrano G, Grassi M, Notarnicola M. Characteristics and adsorption capacities of low-cost sorbents for wastewater treatment: A review. Sustainable Materials and Technologies. 2016 Sep 1;9:10-40.
32) Kaykhaii M, Sasani M, Marghzari S. Removal of dyes from the environment by adsorption process. Chem. Mater. Eng. 2018;6(2):31-5.
33) Antoniadis A, Takavakoglou V, Zalidis G, Darakas E, Poulios I. Municipal wastewater treatment by sequential combination of photo catalytic oxidation with constructed wetlands. Catalysis Today. 2010 Apr; 151(1-2):114–8.
34) Khataee AR, Vatanpour V, Amani Ghadim AR. Decolorization of C.I., Acid blue 9 solutions by UV/Nnao TiO2, Fenton-like, electro-fenton and electro coagulation processes: a comparative study. Journal of Hazardous Materials. 2009 Jan; 161(2-3):1225–33
35) Babuponnusami A, Muthukumar K. A review on Fenton and improvements to the Fenton process for wastewater treatment. Journal of Environmental Chemical Engineering. 2014 Mar 1;2(1):557-72.
36) Rekhate CV, Srivastava JK. Recent advances in ozone-based advanced oxidation processes for treatment of wastewater-A review. Chemical Engineering Journal Advances. 2020 Nov 15;3:100031.
37) Ebba M, Asaithambi P, Alemayehu E. Development of electrocoagulation process for wastewater treatment: optimization by response surface methodology. Heliyon. 2022 May 10;8(5):e09383. doi: 10.1016/j.heliyon.2022.e09383. PMID: 35592662; PMCID: PMC9111894.
38) Tripathi M, Singh S, Pathak S, Kasaudhan J, Mishra A, Bala S, Garg D, Singh R, Singh P, Singh PK, Shukla AK, Pathak N. Recent Strategies for the Remediation of Textile Dyes from Wastewater: A Systematic Review. Toxics. 2023 Nov 19;11(11):940. doi: 10.3390/toxics11110940. PMID: 37999592; PMCID: PMC10674586.
39) Kalyani DC, Telke AA, Dhanve RS, Jadhav JP. Ecofriendly biodegradation and detoxification of Reactive Red 2 textile dye by newly isolated Pseudomonas sp. SUK1. J Hazard Mater 2009;163:735-42.
40) Ali H. Biodegradation of synthetic dyes-a review. Water Air Soil Pollut 2010;213:251-73.
41) Carias CC, Novais JM, Martins-Dias S. Are Phragmites australis enzymes involved in the degradation of the textile azo dye acid orange 7? Bioresour Technol 2008;99:243-51.
42) Nigam P, Banat IM, Singh D, Marchant R. Microbial process for the decolorization of textile effluent containing azo, diazo and reactive dyes. Process Biochem 1996;31:435-42.
43) Banat IM, Nigam P, Singh D, Marchant R. Microbial decolorization of textile-dyecontaining effluents: A review. Bioresour Technol 1996;58:217-27.
44) Fulekar MH,Wadgaonkar SL, Singh A. Decolorization of dye compounds by selected bacterial strains isolated from dye stuff industrial area. International Journal of Advancements in Research & Technology. 2013 Jul; 2(7): 182–192.
45) Akansha K, Kaur T, Yadav A, Kour D, Rai AK, Singh S, Mishra S, Kumar L, Miglani K, Singh K, Yadav AN. Microbe-mediated remediation of dyes: Current status and future challenges. Journal of Applied Biology and Biotechnology. 2023 Jun 4;11(4):1-23.

46) Prabha S, Gogoi A, Mazumder P, Ramanathan AL, Kumar M. Assessment of the impact of textile effluents on microbial diversity in Tirupur district, Tamil Nadu. Appl Water Sci 2017;7:2267-77
47) Parmar ND, Shukla SR. Decolourization of dye wastewater by microbial methods-a review. Indian J Chem Technol 2018;25:315-23.
48) Gill PK, Arora DS, Chander M. Biodecolourization of azo and triphenylmethane dyes by Dichomitus squalens and Phlebia spp. J Ind Microbiol Biotechnol 2002;28:201-3.
49) Svobodová K, Senholdt M, Novotný Č, Rehorek A. Mechanism of reactive orange 16 degradation with the white rot fungus Irpex lacteus. Process Biochem 2007;42:1279-84
50) Jayasinghe C, Imtiaj A, Lee GW, Im KH, Hur H, Lee MW, et al. Degradation of three aromatic dyes by white rot fungi and the production of ligninolytic enzymes. Mycobiology 2008;36:114-20.
51) Nair VK, Selvaraju K, Samuchiwal S, Naaz F, Malik A, Ghosh P. Phycoremediation of Synthetic Dyes Laden Textile Wastewater and Recovery of Bio-Based Pigments from Residual Biomass: An Approach towards Sustainable Wastewater Management. *Processes*. 2023; 11(6):1793. https://doi.org/10.3390/pr11061793
52) M. Mahmoud. Decolorization of certain reactive dye from aqueous solution using Baker's Yeast (Saccharomyces cerevisiae) strain. HBRC Journal, 12, pp. 88-98, 2016.
53) Z. Aksu. Reactive dye bioaccumulation by Saccharomyces cerevisiae. Process Biochemistry, 38, p. 1437–1444., 2003.
54) Farah JY, El-Gendy NSh, Farahat LA. Biosorption of Astrazone Blue basic dye from an aqueous solution using dried biomass of Baker's yeast. J Hazard Mater. 2007 Sep 5;148(1-2):402-8. doi: 10.1016/j.jhazmat.2007.02.053. Epub 2007 Feb 27. PMID: 17400371.
55) Yan A, Wang Y, Tan SN, Mohd Yusof ML, Ghosh S, Chen Z. Phytoremediation: a promising approach for revegetation of heavy metal-polluted land. Frontiers in Plant Science. 2020 Apr 30;11:359.
56) Prol A, Azzem M, Amer A, El-Metwally M, El-Hamid H, El–Moselhy K. Adsorption of Cadmium (II) Ions (II) from Aqueous Solution onto Mango Leaves. Asian Journal of Physical and Chemical Sciences. 2017 Jan 10;2(3):1-1.
57) Bulgariu L, Escudero LB, Bello OS, Iqbal M, Nisar J, Adegoke KA, Alakhras F, Kornaros M, Anastopoulos I. The utilization of leaf-based adsorbents for dyes removal: A review. Journal of Molecular Liquids. 2019 Feb 15;276:728-47.
58) Kovacic P, Somanathan R. Toxicity of imine-iminium dyes and pigments: electron transfer, radicals, oxidative stress and other physiological effects. J Appl Toxicol. 2014 Aug;34(8):825-34. doi: 10.1002/jat.3005. Epub 2014 May 22. PMID: 24852913.
59) Hussain B, Sajad M, Usman H, A Al-Ghanim K, Riaz MN, Berenjian A, Mahboob S, Show PL. Assessment of hepatotoxicity and nephrotoxicity in Cirrhinus mrigala induced by trypan blue - An azo dye. Environ Res. 2022 Dec;215(Pt 1):114120. doi: 10.1016/j.envres.2022.114120. Epub 2022 Aug 24. PMID: 36029837.
60) Saleh A. Almatroodi, Ahmad Almatroudi, Shehwaz Anwar, Ali Yousif Babiker, Amjad Ali Khan, Mohammed A. Alsahli & Arshad Husain Rahmani (2020) Antioxidant, anti-inflammatory and hepatoprotective effects of olive fruit pulp extract: *in vivo* and *in vitro* study, Journal of Taibah University for Science, 14:1, 1660-1670, DOI: 10.1080/16583655.2020.1848761
61) Anwar S, Almatroudi A, Alsahli MA, Khan MA, Khan AA, Rahmani AH. Natural Products: Implication in Cancer Prevention and Treatment through Modulating Various Biological Activities. Anticancer Agents Med Chem. 2020;20(17):2025-2040. doi: 10.2174/1871520620666200705220307. PMID: 32628596.
62) Yahia, E.A., & Anwar, S. (2021). Indicators and risk factors associated with Malnutrition among patients with Liver Cirrhosis: Nursing Perspective. IJCRT, 8(3), 3255-3269.
63) Anwar S, Kumar V, Kanwal B, Yahia EA. (2023). A Review on Utilization of Ashoka Plant in Oxidative Stress Induced Women Reproductive Health Complications. IJCRT, 11(9), f249-f258.
64) Rahmani AH, Babiker AY, Anwar S. Hesperidin, a Bioflavonoid in Cancer Therapy: A Review for a Mechanism of Action through the Modulation of Cell Signaling Pathways. *Molecules*. 2023; 28(13):5152.
65) Anwar S, Raut R, Kanwal B, Yahia EA. Kumar V, (2022). In Vitro Investigation of Anti-inflammatory and Antioxidant Activities of Curcuma Longa Rhizome Methanol Extract. IJCRT, 10(10), c559-c581.
66) Anwar S, Almatroudi A, Allemailem KS, Jacob Joseph R, Khan AA, Rahmani AH. Protective Effects of Ginger Extract against Glycation and Oxidative Stress-Induced Health Complications: An In Vitro Study. Processes. 2020; 8(4):468. https://doi.org/10.3390/pr8040468.
67) Rahmani AH, Anwar S, Raut R, Almatroudi A, Babiker AY, Khan AA, Alsahli MA, Almatroodi SA. Therapeutic Potential of Myrrh, a Natural Resin, in Health Management through Modulation of Oxidative Stress, Inflammation, and Advanced Glycation End Products Formation Using In Vitro and In Silico Analysis. Applied Sciences. 2022; 12(18):9175. https://doi.org/10.3390/app12189175.

68) A.TAMILARASI, M. Bhanuchitra. CLASSIFICATION AND TYPES OF NATURAL DYES: A BRIEF REVIEW. International Journal of Creative Research Thoughts. 2021, 9(11), 527-532.