Journal of King Saud University – Science 34 (2022) 101775

Contents lists available at ScienceDirect

Journal of King Saud University – Science

journal homepage: www.sciencedirect.com

Original article

Application of wheat bran based biomaterials and nano-catalyst in textile wastewater

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ARTICLE INFO

Article history:
Received 14 November 2021
Revised 8 December 2021
Accepted 14 December 2021
Available online 22 December 2021

Keywords:
Textile
Wheat bran
Dyes
Biosorption
Adsorbent
Adsorption
Wastewater
Effluent
Enzyme

ABSTRACT

The exponential expansion of industrial production during the past few decades has been detrimental to the environment owing to increased contamination with chemical pollutants such as heavy metals and dyes. Each year, large volumes of agricultural byproducts are generated as waste materials from various food crops, one which is wheat bran from wheat, the world's largest food crop. Approximately 12% of dyes made from synthetic materials used by the textile industry are lost in the production and processing phases; similarly, 20% of the resulting dye reaches the ecosystem via industrial wastewater effluents. These dyes are highly radioactive and have potentially negative consequences; therefore, several federal and environmental authorities have enacted stringent regulations and restrictions prohibiting the dumping of dye-containing raw sewage into existing water bodies. Although there are several methods to remove dye from wastewater, the preferred approach is adsorption. Activated charcoal is one of the best adsorbents. However, its use in industrial water treatment, mainly in developing nations, is confined because of its high cost. Owing to the increasing price of activated carbon, researchers have been tasked with developing a low-cost, reliable adsorbent that can be substituted for activated carbon. Several adsorbents, such as biosorbents, carbon-based nano-adsorbents, transition metal-based oxides, Metal-organic frameworks MOFs, and polymer-based adsorbents, are used to treat dye-containing wastewater. This chapter compiles the results of various studies that analyzed the use of wheat bran as an absorbent for eliminating dyes and other toxic effluents from the textile industry. Dye removal via adsorption and nano-materials is expected to be a promising method for the treatment of dye-laden water.

1. Introduction

Industrial effluents from a wide range of industries are a major source of environmental concern. In recent years, wastewater management has played a critical role in avoiding pollution and protecting the water supply. Conventional wastewater treatment is expensive and generates sludge. The low cost and complex composition of wheat bran make it an excellent source for the processing of different enzymes and organic acids, as well as for several biotechnological processes (Dotto et al., 2017; Khan, 2020). The adsorbent determines the process cost. For example, commercial activated carbon costs Rs. 500/kg, whereas bioadsorbents cost between Rs. 4.4–36.89/kg, which is substantially cheaper than commercial adsorbents (Gupta and Babu, 2008). Pollution of the environment due to many factors has been an increasing issue in recent years. Owing to the constant existence of various dyes, the release of dyes into wastewaters by numerous factories raises severe environmental problems. When dyes are emitted in trace amounts, their origin in rivers is easily detectable (Robati et al., 2016).

Effluent containing dye(s) from the textile industry is challenging to treat owing to the dyes' complexity, tolerance to aerobic digestion, and sensitivity to sunlight, temperature, and oxidants (Jadhav and Jadhav, 2021). Many chemical, physical, and biological decolonization processes have been described over the last three decades. Flocculation, coagulation, activated carbon adsorption, biodegradation, ion exchange, membrane separation, oxidation, selective biosorbents, and advanced oxidation are some of the processes (Abhinav et al., 2021). Such approaches also have

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Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

https://doi.org/10.1016/j.jksus.2021.101775
1018-3647/

drawbacks, including insufficient removal efficiency, high reagent and resource requirements, and the production of radioactive materials or other waste materials, which must be properly disposed of and treated accordingly. These strategies are expensive, thereby rendering them economically and commercially unviable (ZivkoJovanovic et al., 2006). Modified carbon has a high dye removal capacity via adsorption, which is primarily attributed to its broad, permeable surface and molecular composition, which can be easily enhanced by chemical treatment (Robati et al., 2016). Interest in developing alternate adsorbents to substitute enabled carbon has increased in recent decades (Wang et al., 2002). Agricultural waste products have been suggested as cost-effective and environmentally safe adsorbents. Agricultural materials, particularly those including cellulose, exhibit a strong potential for dye biosorption. In recent decades, greater focus has been given to the utilization of metal oxide nano-particles in dye water treatment. Metal oxide nano-particles can be enhanced by combining them with alternative materials to overcome the limits of such particles, such as porous support materials used as a matrix (Ayed et al., 2011; Burakov et al., 2018; Tamiru and Bekele, 2020). Wheat bran biomaterial, a relatively inexpensive and readily accessible material, has been effectively used as an adsorbent for dye removal from wastewater. Thus, it is inferred that wheat bran is significantly more affordable, efficient, and viable than more expensive adsorbents (Zhai et al., 2021).

2. Literature review methodology

The relevant literature was searched using the keywords Biomaterial and Nano-catalyst in dye industries" (as of July 2021) in Scopus and Web of Science to understand the current significance of this research. Fig. 1 shows the different subject areas in which biomaterials and nano-catalysts are used in the dye industry. The results were narrowed down to the last two decades by specifying a time range from 2005 to 2021 (Fig. 1a and b summarizes the number of papers describing biomaterials used in dye bioremediation from 2005 to 2021). The number of papers on bioremediation of textile effluents has increased in recent years. We also observed a significant increase in the number of research publications on biomaterials in the dye industry from 2005 to 2020.

3. Agricultural byproduct-based wastewater treatment

Agricultural and animal waste products are the primary sources of bio-adsorbents. Agro-based byproducts have been chosen for wastewater treatment because they are plentiful in nature, easily accessible, and less expensive (Chakraborty et al., 2020). Apart from wheat bran; rice husk, walnut shell, almond husk, sawdust, and sugarcane bagasse have all been used for synthetic dye adsorption. Agricultural byproducts have received much attention for their ability to remove toxic ions from liquid textile waste (Dahri et al., 2014; Sarkar, 2010; Sulak and Yatmaz, 2012).

3.1. Wheat bran

Following rice, wheat is the second most widely grown cereal grain for human consumption. China is the leading country in terms of wheat output. China produced 134 250 thousand tons of wheat in 2020, followed by India, the Russian Federation, the USA, and Canada, accounting for 64.63% of the total. The wheat output in India in 2018–2019 was 99.7 MT (Das, 2019). Global wheat output in 2020 was 772.64 million metric tons. Wheat production is expected to reach a new high of 109.24 MT in 2020–2021, up from 107.86 MT in the previous year (Oluwatoyin et al., 2015; Shuang-Qi et al., 2017). Wheat bran is a milling byproduct that has both food and non-food properties. The industrial use of wheat bran has steadily expanded over time (Hossain et al., 2013).

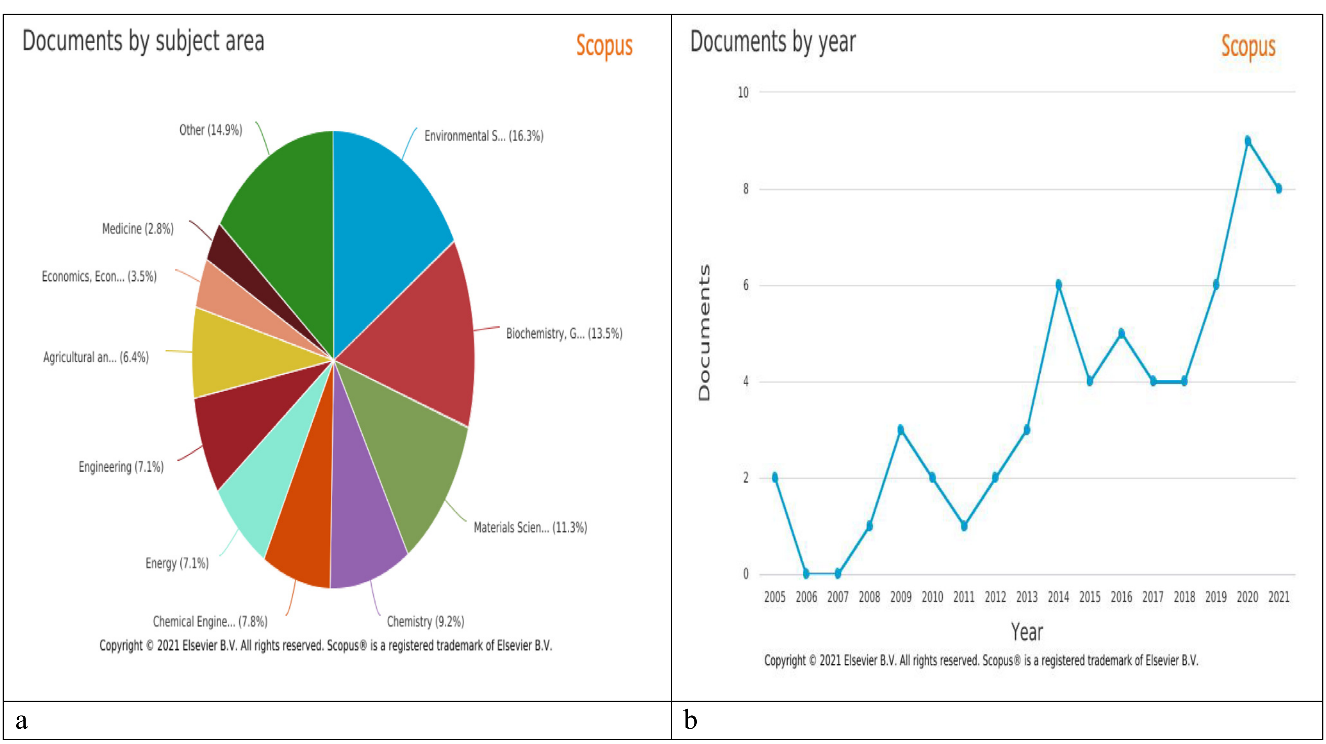

Fig. 1. a. Analysis of number of subject area describing dye bioremediation by Biomaterials from 2005 to 2021 (1b) Analysis of number of papers describing dye bioremediation by Biomaterials from 2005 to 2021.

3.2. Wheat bran chemical composition

Wheat bran/straw have higher mineral contents, including K, Na, and Mg, whereas wheat bran has a higher heavy metal content, including Pb, Zn, Mn, and Ni (Youna et al., 2007). Agro-based byproducts are made up of bioactive groups in the form of cellulose, hemicellulose, lignin, ligno-humic substances, starch, sugars, and polysaccharides (Mohan and Pittman, 2006; Sud et al., 2008). Wheat bran is a good source of dietary fiber because it includes 46% non-starch polysaccharides, which include cellulose (24%), beta-glucan (6%), arabinoxylan (70%), and trace quantities of arabinogalactan and glucomannan (Hemery et al., 2007). Wheat bran often includes phenolic acids, carotenoids, and tocopherols (Fardet, 2010; Menga et al., 2010) (Fig. 2).

3.3. Textile industry

The textile industry is one of the largest and most important production networks in the world. The clothing industry produces a broad range of pollutants at various levels of the fiber, fabric, and apparel manufacturing processes (Srebrenkoska, 2014). Textile mills supply the raw material for the production of clothing and textile goods. They convert natural and synthetic fibers, such as cotton and polyester, into thread, and fabric (Khalili et al., 2017).

3.3.1. Textile effluent treatment techniques

The major environmental issue with the textile industry is the quantity and chemical load of water discharged. Recent years have seen an increase in involvement in dye removal as government laws regulating the emission of hazardous effluent have grown increasingly strict. Wastewater decolorization has been achieved using physical and chemical processes such as foam flotation, electrolysis, coagulation, ozonation, oxidation, filtration, photo catalysis, biological oxidation, electrochemical treatment, adsorption, flocculation, and membrane separation techniques (Lee et al., 2006) (Fig. 3). The textile manufacturing sector uses a large amount of water. Water is used as a raw material and for several scrubbing measures throughout the manufacturing phase. Approximately 200 L of water is utilized to produce 1 km of textile (Srebrenkoska, 2014).

Electrocoagulation and flotation have been used to dissolve water-soluble, complex-structured reactionary textile dyes with minimal effectiveness. Activated sludge and aerobic and anaerobic procedures are examples of biochemical methods (Kamaruddin et al., 2013). These processes have high operational costs, a lengthy protocol, and contain hazardous chemical derivatives (He et al., 2021; Santhi et al., 2016).

3.3.2. Textile dyes

Dyes are substances that, when combined with a substrate, provide a color effect and also impart color by a mechanism that briefly changes the crystal structure of the colored substances.

Many forms of fabric dyes are used in the textile industry. There are two major categories of dyes, namely natural dyes and synthetic dyes. Natural dyes are created by removing natural pigments from plants, animals, and minerals, whereas synthetic dyes are produced in a factory (Bulut and Karaer, 2015; He et al., 2018; Munir et al., 2020; Ogugbue and Sawidis, 2011) (Fig. 4).

The majority of these dyes evade traditional wastewater treatment systems and remain in the atmosphere owing to their high resistance to water, temperature, additives, soap, detergents, and other environmental factors such as bleach and perspiration (Couto, 2009). In terms of the number of textile industries and the rate of output, azo dyes are the most prevalent type of dye, accounting for 60–70% of all organic dyes manufactured globally (Bafana et al., 2011). The effectiveness of azo dyes is connected to the simplicity of production and cost benefits in comparison with those of natural dyes, as well as their strong structural richness, strong molar absorption coefficients, and modest light and moisture fastness (Bafana et al., 2011; Ben Mansour et al., 2007;

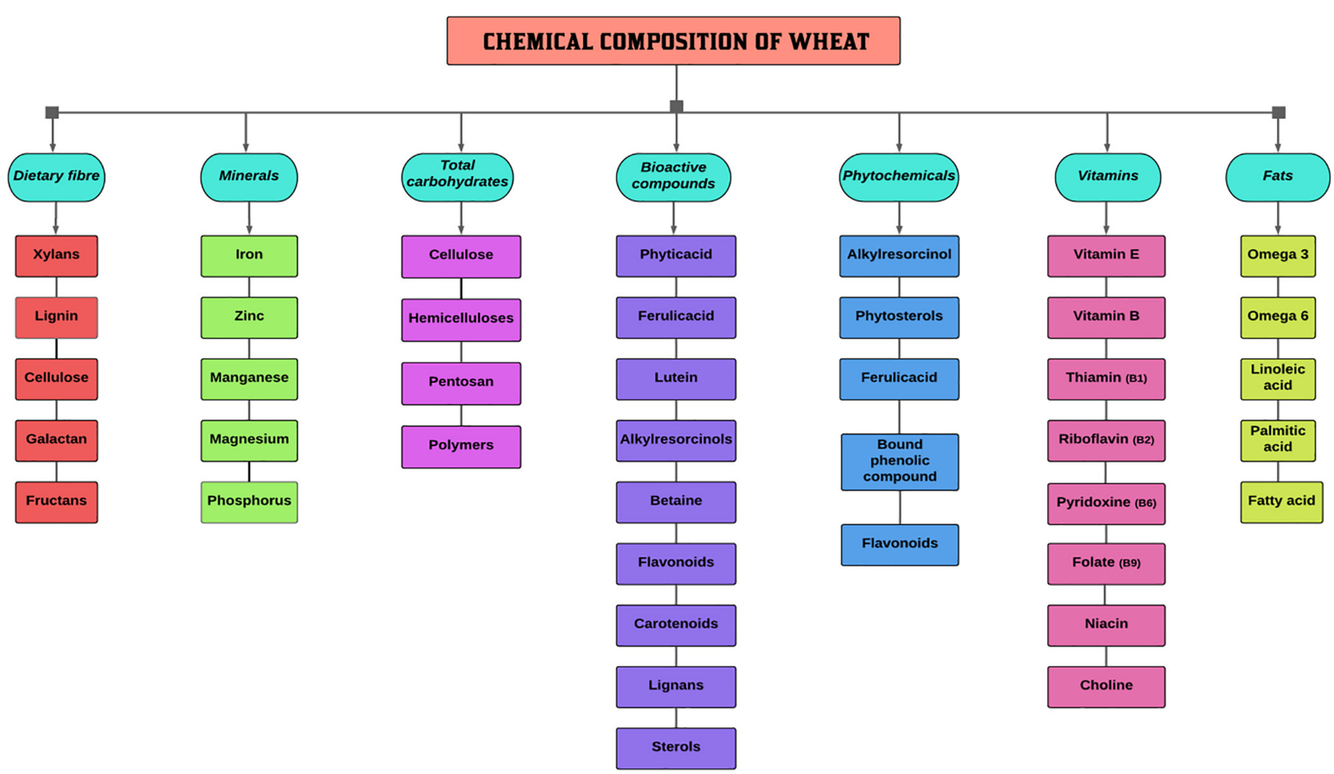

Fig. 2. Chemical composition of Wheat.

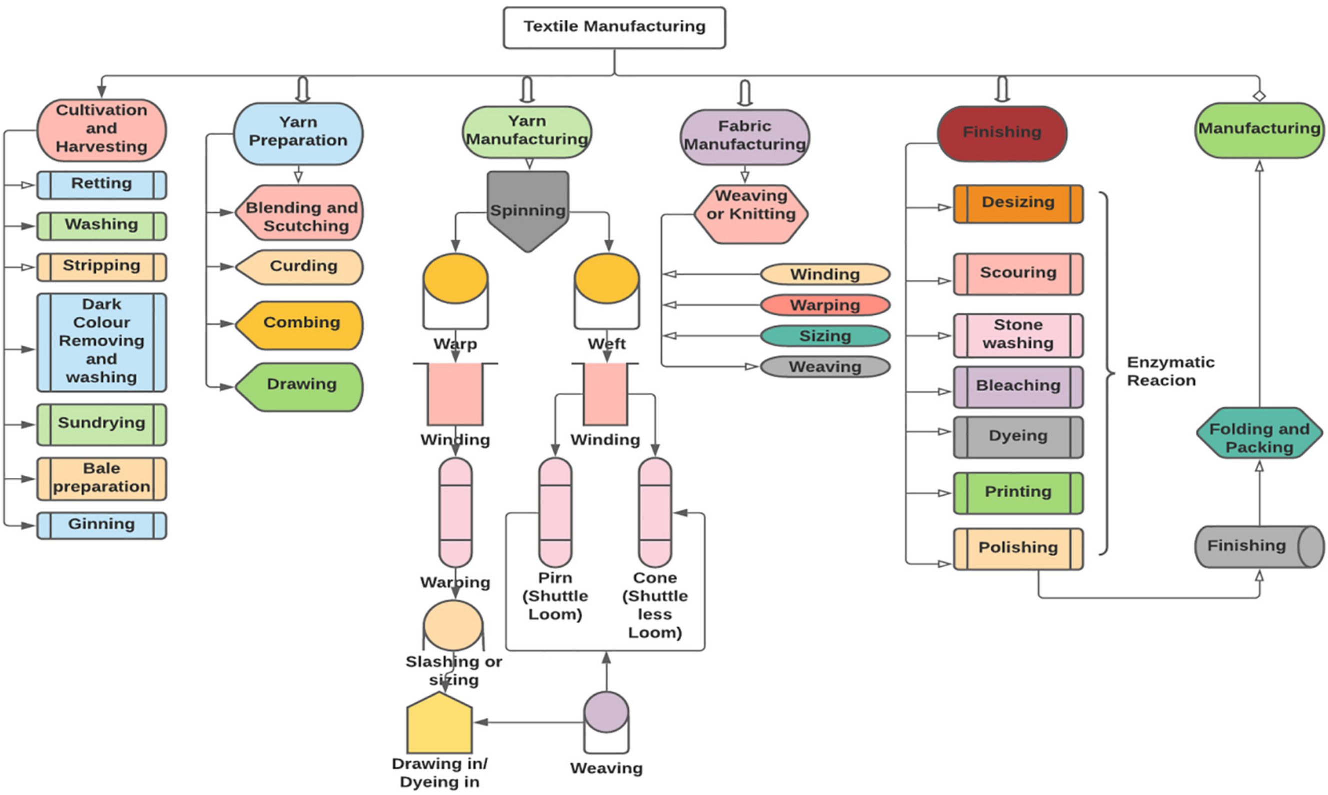

Fig. 3. Textile Manufacturing Process.

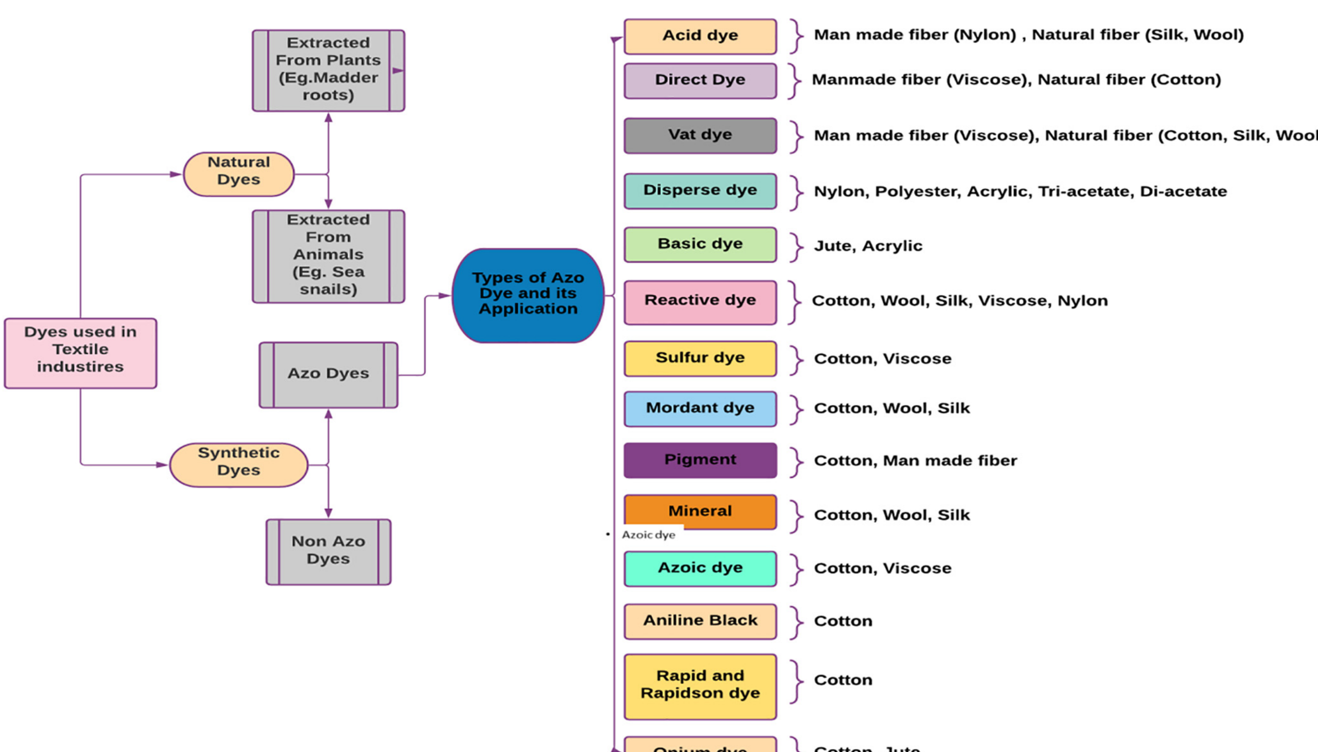

Fig. 4. Dyes Used in Textile industries and its Application.

Seesuriyachan et al., 2007). In addition, the impact of other toxins and the accumulation of very limited concentrations of dyes (1 mg/L for certain dyes) in the water that are highly noticeable have a detrimental influence on the aesthetic appearance and clarity of bodies of water, such as reservoirs and rivers, thereby resulting in harm to the marine ecosystem (Wijetunga et al., 2010).

3.4. Biosorption

Biosorption is a procedure that uses biological materials as adsorbents. This approach has been investigated by many researchers as a substitute for conventional approaches for the recovery of toxic materials from wastewater. Biosorption with low-cost agricultural residues such as rice husk, sugarcane dust, and wheat bran is a large bioremediation technique with moderate cost. These cellulose and hemicellulose matrixes, which include a broad range of functional groups, efficiently bind dyes via different mechanisms. As a result, the use of certain biomaterials, both processed and unmodified, significantly enhances dye adsorption from substances (Djilali et al., 2012) (Fig. 5).

3.4.1. Wheat bran as a biosorbent

Although wheat bran serves as a biosorbent and the adsorbed content is degraded during the biodegradation phase, it can also serve as a biosorbent for a variety of inorganic and organic toxic compounds that are not often degradable (such as heavy metal ions). Wheat bran is one of the best sources of cellulose and lignin, which function as adsorbent materials during the biosorption phase (Prückler et al., 2014).

3.4.2. Wheat bran as a potential carrier for enzyme immobilization

The capability of *Paenibacillus chitinolyticus* CKS1 in immobilizing glucosidase, cellulase, xylanase, and peroxidase by utilizing other lignocellulosic wastes from wheat bran was explored (Nagar et al., 2014). Xylanase was physically immobilized using wheat bran, which is the outer shell of the wheat kernel that is often removed during the milling process. It has also been used to immobilize cells for the processing of probiotic yoghurt using *Lactobacillus casei* in tandem with *Lactobacillus bulgaricus* (Diorio et al., 2021). Alkali treatment of wheat bran improved the viability of both strains and helped to preserve high viable cell numbers during storage at 4 °C (Terpou et al., 2017). Delignified bran was used to immobilize *Lactobacillus paracasei* K5 cells and to develop usable Cornelian cherry beverages with symbiotic potential (Mantzourani et al., 2019). Fermentation of *Propionibacterium freudenreichii* by in situ vitamin B12 fortifications in wheat flour and bran provided promising results (Xie et al., 2018).

3.4.3. Wheat bran as an adsorbent in heavy metal removal

To successfully eliminate Cr(VI) from wastewater, wheat brans are widely used in many industries. The chromium adsorption value was proportional to the contact time and reached equilibrium at 180 min for wheat bran and 200 min for modified wheat bran. The initial Cr(VI) concentration in the solution process, as well as the pH of the bulk solution, affected the adsorption quantity. The maximum removal of Cr(VI) was 310.58 mg/g at a pH of 2.0 with an original Cr(VI) concentration of 200 mg/L and temperature of 40 °C (Singh et al., 2009; Singha et al., 2006) Cr(VI) has been removed using wheat bran and modified wheat bran. Chemical alteration has been accomplished using citric and tartaric acids. Accordingly, wheat bran and modified wheat bran separated 89.5% of Cr(VI) from the solution (Kaya et al., 2014). Pb(II) was removed from wastewater using wheat bran as an adsorbent (Yasemin and Zübeyde, 2006) Wheat bran's sorption potential for Pb(II) improved as the temperature increased, thereby suggesting that the sorption mechanism was endothermic in origin (Yasemin and Zübeyde, 2006; Das et al., 2019).

3.4.4. Wheat bran as a source of enzyme production

When wheat grain and wheat straw (1:9) were used as substrates, the endoglucanase yield improved by a factor of 26.5. Using wheat bran as a substrate, *Aspergillus niger* B03 (Dobrev et al., 2007), *Aspergillus foetidus* (Chapla et al., 2010), and *Streptomyces*

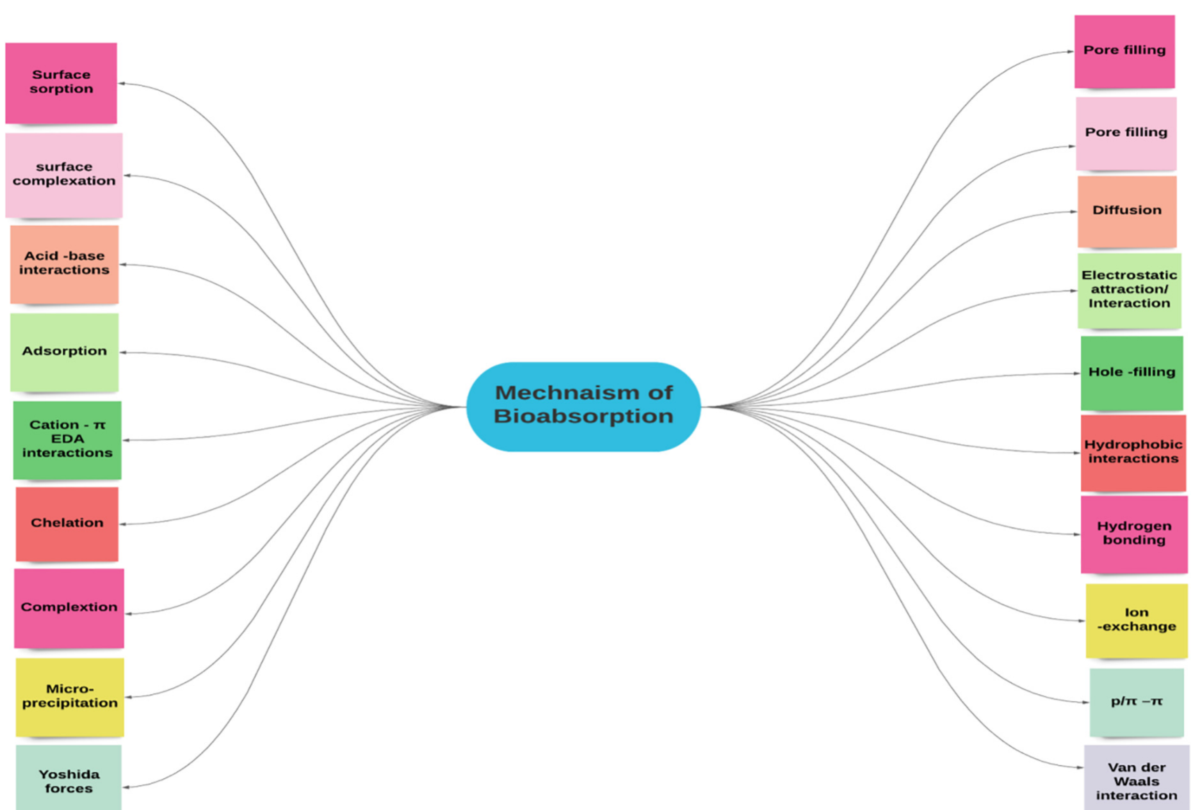

Fig. 5. Mechanism of Biosorption.

thermocarboxydus TKU045 (Thi Ngoc Tran, 2021) produced xylanases; *Bacillus pumilus* produced exo-pectinases (0.4 U/mL) (Tepe and Dursun, 2014; Muthukumarasamy et al., 2015) *Streptomyces* sp. CN902 showed increased production (17.7%) of alkaline protease (Lazim et al., 2009); *Trichoderma reesei* RUT C30 produced cellulase (Sukumaran et al., 2009); and *Aspergillus oryzae*, *Aspergillus flavipes*, and *Penicillium roqueforti* showed maximum proteolytic activity at an alkaline pH. *Aspergillus niger* 40018 and *Aspergillus brasiliensis* produced more enzymes at an acidic pH. However, proteases from *A. brasiliensis* showed a maximum enzymatic activity at a pH of 7 (Novelli et al., 2016). *Aspergillus niger* LBA 02 produced greater proteolytic activity (De Castro et al., 2015). Using wheat bran, *Penicillium chrysogenum* synthesized amylase at a pH of 3, which has wide application in the textile industry, and alkaline medium showed promising results (Dar et al., 2015). Wheat straw wastes were more suitable for α, β, and γ-amylase synthesis by *Bacillus amyloliquefaciens* (Abd-Elhalem, 2015). Wheat straw was the most suitable substrate, and the maximum amount of laccase was synthesized by *Ganoderma lucidum* (Iqbal et al., 2011). The use of wheat bran as a substrate also enhanced the production of the biosolvent butanol by *Clostridium beijerinckii* ATCC 55025 (Liu et al., 2010). Organic acid such as lactic acid was produced by *Bacillus coagulans* IPE22, *Lactobacillus amylophilus* GV6, and *Lactobacillus* sp. RKY2, and succinic acid was produced by *Actinobacillus succinogenes* (Leung et al., 2012) when wheat bran/straw were used as the sole carbon source (Zhang et al., 2014; Novelli et al., 2016)

3.4.5. Wheat bran as an adsorbent in dye removal

Dye polymers used in the textile industry may also pose a concern if they are anaerobically deteriorated in the sediment because toxic amines are often produced as a consequence of incomplete bacterial degradation. Certain dyes and their metabolites are poisonous, mutagenic, or carcinogenic (Boushehrian et al., 2020; Zhang et al., 2020) (Fig. 6). Cellulose and lignin are the major elements of wheat bran that can absorb dye cationic and anionic ions. However, the origin of specific biomolecules influences their binding potential for both ions (Boushehrian et al., 2020). The functional classes in pectin and hemicellulose have the capacity to bind toxic metals. Wheat bran includes a variety of organic functional groups according to X-ray diffraction and infrared tests. Adsorption of reactive blue 19, reactive red 195, and reactive yellow 145 by wheat bran, a lignocellulosic byproduct, increased as the temperature and initial dye concentration increased, whereas the adsorption decreased as the initial pH and adsorbent concentration increased (Cicek et al., 2007).

External and internal diffusion fasten the adsorption level of toxic methylene blue (Hamdaoui and Chiha, 2007). Electrostatically altered nano-particles have recently received much interest in wastewater treatment. The maximum removal efficiencies of Methlene blue and Methlene violet dyes were 97.46% and 98.75%, respectively, utilizing the wheat bran/Fe_3O_4 hybrid (Pooladi et al., 2021). The absorption of methyl orange (MO) using multi-walled carbon nanotubes (MWCNTs) revealed that raising the starting colour concentration enhanced the MO adsorption capability (Tanhaei et al., 2020). Wheat bran was found to be efficient at separating reactive red 180, reactive black 5, reactive orange 16, direct red 80, acid red, and acid yellow 199 from aqueous medium in biosorption applications (Sulak and Yatmaz, 2012). Basic dyes such as malachite grey, crystal violet, and rhodamine B were adsorbed faster when activated carbon on wheat bran was enhanced with *Thevetia peruviana* (Baseri et al., 2012). The adsorptive potential of wheat bran for the elimination of crystal violet from industrial wastewater was effective at a pH of 8, temperature

Fig. 6. Novel Application of Bioadsorbent.

of 30 °C, adsorbent concentration of 10 g/L, adsorption time of 180 min, and adsorbate concentration of 100 mg/L, removing approximately 88% of crystal violet from aqueous solution with a maximum adsorption capacity (qm) of 25.66 mg/g (Shalini, 2019).

In a batch reactor, wheat bran was thermochemically adjusted with citric acid to serve as a possible adsorbent for the removal of malachite green (Shamik and Saha, 2013; Wang et al., 2002) Operational parameters such as the solution pH, adsorbent dosage, initial adsorbate concentration, and temperature had a significant effect on the adsorption performance (Jia et al., 2012). Researchers have analyzed the sorption of Coomassie brilliant blue from aqueous solution on wheat bran. The adsorption activity of Coomassie brilliant blue on wheat bran was investigated over a range of pH values, doses, and durations (Meral and Cengiz Yatmaz, 2012). Under optimal conditions, it was found that up to 95.70% of dye could be adsorbed from the solution onto the wheat bran (Ata et al., 2012; Mohsin et al., 2014). The release of trypan blue into the environment poses significant health risks to humans owing to its increased mutagenicity and resistance to microbial degradation due to its fused aromatic ring. Under submerged conditions, wheat bran has been used for the biodegradation of the benzidine-based carcinogenic dye trypan blue (Achak et al., 2013; Harshad et al., 2015).

3.4.6. Nano-particle-based treatment

Fe_3O_4 nano-particles have been used to enhance the surface characteristics of wheat bran. Fe_3O_4 composites have a cubic inverse spinel structure that helps to remove MB and MV dyes. The composite is low-cost and may be utilized to treat wastewater containing cationic dyes (Chauhan and Choudhury, 2021; Pooladi et al., 2021). Electrostatically altered nano-particles have recently received great interest for use in wastewater treatment. The maximum removal efficiencies of MB and MV dyes were 97.46% and 98.75%, respectively, when utilizing the wheat bran/Fe_3O_4 hybrid (Pooladi et al., 2021). Graphene is a two-dimensional carbon nanomaterial with a high specific surface area and exceptional chemical stability. Hu et al. (2013) removed copper from wastewater using sulfonated graphene oxide and modified wheat bran. The sulfo functional group added to graphene oxide is said to boost adsorption capacity. The electrostatic interaction between the functional groups on the surface of the O-ECNFs and MB dye increased the adsorption capacity towards MB dye (170 mg g1) compared to pristine ECNFs (32.5 mg g1) at 25 °C (Thamer et al., 2019). With wheat bran adsorbent, TiO2 and ZnO nanoparticles are affordable, non-toxic, and capable of eliminating developing pollutants from wastewater (Yang et al., 2015).

4. Conclusion

In the past several decades, textile industrial growth has resulted in a rise in the use of heavy metal ions, thereby resulting in a major environmental problem. There have been many efforts to identify an appropriate corrective treatment for heavy metals owing to their toxic and bioaccumulative nature. Many traditional techniques, such as ion exchange, chemical precipitation, coagulation, membrane separation, reverse osmosis, and adsorption, have been utilized to remove pollutants, but these approaches have proven ineffective owing to a number of problems and disadvantages. The adsorption process is extremely helpful and efficient for removing heavy metal ions, even at low concentrations. Thus, the development of low-cost, widely accessible adsorbents for the adsorption of dyes from wastewater has been critical. Agricultural and household wastes; sea materials are the most commonly used low cost bioadsorbent in waste water treatment

Dye removal from wastewater from numerous dye consuming sectors, such as textile industries, has been a major source of concern in recent years because synthetic dyes are prone to chemical, photochemical, and microbial degradation. Numerous techniques have been used to remove dyes and other chemical pollutants from garment drainage, including coagulation, filtration with coagulation, precipitation, ozonation, adsorption, reverse osmosis, ion exchange, and advanced oxidation processes. according to standards of US EPA the permissible limit to discharge is COD, less than 250 mg/L and BOD is less than 30 mg/L (US EPA 2010). In this case, the low cost of adsorbents is ideal techniques for small-scale developers to satisfy the upper limit in eliminating the industrial effluents in water bodies. Green chemistry and nano-catalysts have established a strong presence in all spheres of science and technology, from synthesis methods to treatment technologies. Thus, the use of wheat bran and straw as biomaterials many offer a low-cost approach to the problem of textile wastewater management.

Conflict of interest

The authors have no conflicts of interest.

Acknowledgement

This work was carried out with the support of 'Cooperative Research Program for Agriculture Science and Technology Development (Project No. PJ01529302)' Rural Development Administration, Republic of Korea.

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