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# Synthesis and Characterization of (Clove Extract Doped Se/SnO₂) Granular Green Nanoparticles, and Study Some of Their Applications in Removal Congo Red Dye

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*Abstract*

The study indicates the most recent research that employed the clear precipitation process to raise multiple and diverse amounts using different plant extracts because of its selenium minerals and some metal oxides such tin oxide ($SnO_2$), clove (Clove) was used. As a result, the compound (Clove Extract-$SnO_2$Se) was synthesized. When X-ray diffraction and full-spectrum X-ray diffraction (XRD) were examined, a nano crystalline structure was indicated by the distinct diffraction peaks. Despite being integrated into the crystal lattice strength and nano crystalline characteristics, selenium's X-ray diffraction (XRD) data in the $SnO_2$ crystal lattice did not significantly alter. The catalyst was examined using electron microscopy (ESM), and the findings indicated that a greater surface area differential might lead to agglomeration. Lastly, the recycling process—which involves removing dyes from water—was examined.

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## 1. INTRODUCTION

Azo dyes are the best choice for a coloring component. These are an important class of dyes, accounting for about two-thirds of all synthetic dyes and more than 50% of annual global manufacturing (Benkhaya, S. 2020, Ardila-Leal 2021 and Ismail 2019). Azo dyes are regarded as harmful, mutagenic, and carcinogenic substances that can be either water-soluble or water-insoluble. A dye or its metabolites could be the carcinogen. The metabolite of water-soluble dyes is the carcinogen that the body absorbs most easily (Bhavana 2025). A longer duration is explained by the detrimental effects of azo dyes on the ecology. One of the main causes of dyes' toxicity is their intricate aromatic structures, which rely on an aromatic ring (Giˇcevi´c, 2019). The chemical formula of Congo-red (CR), an azo dye, is C32H22N6Na2O6S2, and its molecular weight is 696.68 g mol1. In 1884, Paul Bottinger identified CR as the first direct dye (Yates, E, 2016) Common names for this anionic di-azo dye (which has two groups -N=N-) include CR 4B, C.I. 22120, Cotton red B, Cotton red C, Direct red 28, Cosmos red, Direct red Y,and Direct red R (Lekshmi, 2022, Tara, 2020 and Abdul, 2024). It is made of a sodium salt of benzidinediazo-bis-1-naphthylamine– 4 - sulfonicacid. The benzene structures in CR are connected to two azo (-N=N-) chromophores and acidic auxochromes (-SO3H) (Maurice, 2010). Another name for CR is acidic diazo dye.CR molecules have linear symmetry and a hydrophobic core made up of two phenyl rings joined by a di-azo bond (Ashok Kumar, 2021), as shown in Figure 1.

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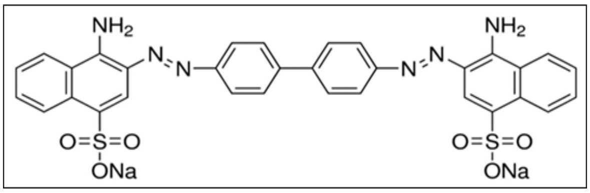


**Figure 1.** Molecular structure of CR. Adapted from the literature (Sharf, 2023)

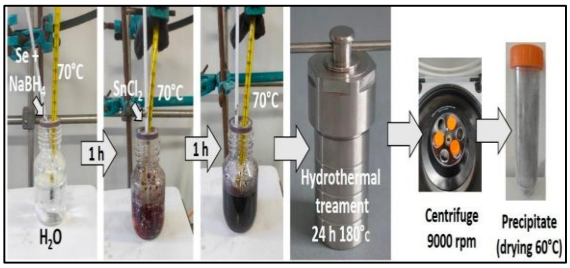
Nano composites can function in a variety of ways. Adsorption and photo catalysis are the most prevalent. The dye adheres to the Nano composite's surface during adsorption because of its vast surface area and active sites, which draw the dye in (Omidvar, 2017). The material is activated by light in photo catalysis, which results in the production of highly reactive species that disassemble the dye molecules (Al-Rawashdeh, 2020). Some systems even combine the two approaches; these hybrid systems are more effective and are being considered for practical application. When exposed to light, semiconductor Nano composites like ZnO, $TiO_2$, and Ag/ZnO are used in photo catalysis, an improved oxidation process, to break down dye pollutants. Complex dye molecules are broken down into innocuous byproducts like carbon dioxide and water by ROS such hydroxyl radicals (•OH) and superoxide radicals ($O_2{\bullet}^-$) (Rustembekkyzy, 2024). A number of variables, including light intensity, catalyst composition, reaction time, and the presence of oxidizing chemicals, affect how effective photo catalysis are (Palani, 2023). The capacity of photo catalysis to totally mineralize dye molecules and get rid of secondary waste products is one of its main advantages. However, obstacles like photo corrosion, restricted absorption of visible light, and catalyst stability prevent their widespread use (Farhan, 2023). Photo catalytic endurance and efficiency have been greatly enhanced by recent developments in heterojunction devices, plasmatic photo catalysts, and doped semiconductor Nano composites (Narendra Verma, 2025 and Pattnaik, 2023).

The production of particles or particles with a range of Nano scales is a common use of modern technology, or nanotechnology. The production, processing, and application of various systems, installations, and devices composed of nano-modules are all included in the definition of nanotechnology, which is an advanced field (Malik S, 2023). Nanoparticles have unique properties due to their small size, chemical composition, and surface structure. This technique is used to create nanomaterials to remove water pollutants because of the nanoparticles' enormous surface area and small size, which are essential for bridging the organic and inorganic phases of contaminants (Aslan N, 2022 and Zainab Abas Abdul-Zahra, 2025). Se / $SnO_2$ composites (Li, X., 2023) offer an intriguing fusion of the distinct electrical and optical characteristics of materials based on selenium (Huang, 2021) with the wideband gap semiconductor nature of $SnO_2$. Two semiconducting materials with different local bonding geometries are combined in the Se / $SnO_2$. The following is a rationale. Six oxygen atoms coordinate with tin in the +4 oxidation state in $SnO_2$, which is equivalent to an AX6 configuration. As a result, an octahedral geometry is created, supporting the $SnO_2$ rutile-type crystal lattice. Elements of selenium, on the other hand, usually form helical chains. A bent shape results from each Se atom having two neighbors and two lone pairs, and elucidating the selenium chains' angular shape. The stiff octahedral Sn–O framework is anticipated to interact with the bent Se units at the SnO2-Se contact. At the surface, the lone pairs on Se might interact with Sn or O atoms. To increase performance across a range of devices, this heterostructure can expand light absorption, improve charge carrier separation, and adjust electronic band alignments (Alamo-Nole, 2024). One of the herbs utilized for therapeutic purposes is cloves. It is harvested from a tree as a fruit. The name of this tree is Syzygium aromaticum. It grows in Central Asia in nations like Indonesia, India, Malaysia, and Sri Lanka, and in Africa in nations like Madagascar and Tanzania (Haro-González, 2021). It is a member of the Myrtaceae family. In addition to its many medical applications, Syzygium aromaticum is used in cooking to improve the flavor of various foods. It comes in two forms in the commercial world: powdered and dried flower buds. In reference to the medical domain, Cloves have long been used in traditional medicine (in the form of herbal tea) to treat a variety of conditions, including rheumatism, digestive disorders, tooth discomfort (as an analgesic), inflammation of the mouth and throat, and more (Lynda Sabrina, 2023) Among other spices, cloves are unique because of their potent medicinal qualities for use in pharmaceutical applications, including anti-inflammatory, anti-oxidant, anti-microbial, anti-bacterial, antiseptic, anti-fungal, anti-cancer genic, antispasmodic, and antiviral effects, among others (Mahasin Ahmed Wadi, 2025). Fainally, The purpose of this research paper is to investigate the creation of a nanocomposite using a naturally occurring substance that we all encounter on a daily basis—clove plant extract—and to carry out some useful experiments on it, including photocatalysis and recycling of the produced compound, which can be utilized in the adsorption process of Congo Red dye pollutants and to eradicate their toxicity. It also seeks to investigate the effectiveness of the nanocomposite and its application in enhancing the quality of contaminated water.

## 2. MATERIALS AND METHODS

### 2.1. Synthesis of Se / $SnO_2$ Composites

The synthesis of the Se / $SnO_2$ composite that is added to clove extract (prepared in advanced in a laboratory) was carried out hydrothermally by adding the components in solution in different steps. Initially; an aqueous suspension of selenium and sodium borohydride (NaBH4) was prepared. Selenium powder (Se) was used to form selenium anions by employing sodium borohydride as a reducing agent. In detail, 0.27 g of Se powder were mixed with 0.13 g of NaBH4 in 30 mL of mQ water and stirred homogeneously for 1 h at 70 °C. The initial solution was brown. After 1 h of stirring, 0.08 g SnCl2 · $2H_2O$ were added and stirred for another hour. A dark green solution was initially obtained. As the reaction progresses, a black precipitate forms, accompanied by a yellow supernatant. Then, the solution was transferred to a 50 mL Teflon-lined autoclave for hydrothermal synthesis, heated at 180 °C in an oven in air, and left to react for 24 h. Finally, the solution was centrifuged at 9000 rpm for 15 min, and a black precipitate with a transparent supernatant was obtained, which was then discharged. The precipitate was finally put in an oven in air at 60 °C to dry until a gray-black solid was obtained (Scheme 1). Reference $SnO_2$ was prepared by heating $SnCl_2\cdot 2H_2O$ in an oven in air at 600 °C for 2 h. This method in the preparation was similar to the method adopted by the researcher Stefania and ets. (Stefania Mura, 2025).




**Scheme 1**: Synthesis processes, starting with the Se+ NaBH4 aqueous solution and ending with the final dried powder

### Effect of Some Factors on Congo Red Dye

### 2.2. Weight Effect Experiment

Three weights (0.2, 0.4, 0.6) g of the composite differential extract (clove extract- Se / $SnO_2$) were taken at a concentration of -10 ppm under light (1.71 Mω). The mixture was stirred for 90 minutes.

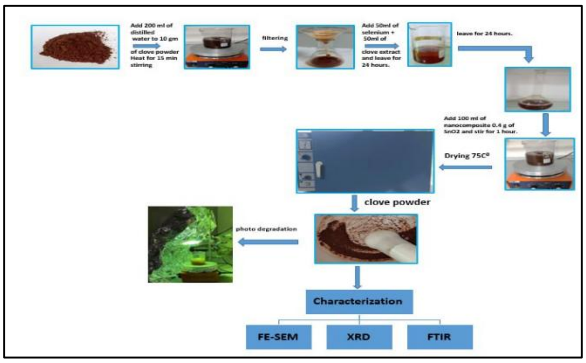
### 2.3. Concentration Effect Experiment

Several concentrations (10, 15, 20 ppm) of the composite nano-extract were taken and left to stand for 90 minutes.

### 2.4. Solvent Effect Experiment

10 ppm of the dye was taken with 0.4 g of the composite differential extract and 1-3 ppm of the solvent ($H2O_2$-CH3OH). The mixture was left to stand for 90 minutes due to dehydration. 7-2: Recycling experiment (removal of the object).

The safety was ensured by taking 0.4 g, ppm 10 concentration of dye for three sub-zero cycles for 90 minutes, as shown in scheme 2.




**Scheme 2**: Schematic diagram of the preparation of the nanocomposite with the extract and the photocatalytic.

## 3. RESULTS AND DISCUSSION

### 3.1. Scanning Electron Microscopy (SEM)

Se-doped $SnO_2$ nanoparticles have a quasi-spherical shape and obvious aggregation, as seen by the SEM image. According to the picture analysis, the surface is irregular and contains particals clustered in clumps, the average particle size is roughly (43.42) nm. Also observed poros led to increased surface area of the nanoparticles and this may be the cause of the observed aggregation. For surface-related applications like gas sensing and photo catalysis, the surface's roughness indicates a potentially high surface-to-volume ratio, as seen in Figure 2.

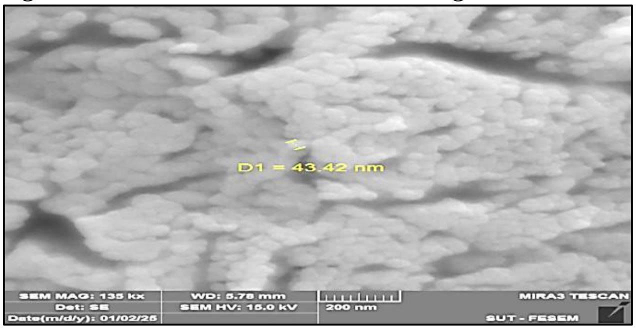



**Figure 2:** SEM for nanoparticles compound synthesed

### 3.2. X-ray Diffraction (XRD)

Figure 2 reflects X-ray diffraction (XRD) tests that reveal the compound (clove extract- Se/$SnO_2$) displays distinct phases. The most popular non-destructive technique for examining the crystalline structures of composite materials is X-ray diffraction (XRD). The production of a well-crystallized tetragonal rutile structure is confirmed by the Se-doped $SnO_2$ X-ray diffraction (XRD) pattern. The distinctive planes of rutile $SnO_2$ can be linked to the diffraction peaks seen at around $2\theta = 31.9°$, 34.5°, 36.4°, 47.7°, 56.8°, 63.0°, and 66–77°, suggesting that the basic crystal structure does not change with the addition of selenium. The presence of multiple indicates many crystalline levels, and are not observed proad peak that led to a missing amorphous phase peak. Within the experimental detection limit, no more impurity peaks were found that corresponded to secondary phases such elemental Se-Sno2 complexes. This implies that rather of forming distinct phases, selenium ions are effectively integrated into the $SnO_2$ lattice. Lattice distortion brought on by the substitution of selenium ions with varying ionic radii for $Sn^{4+}$ ions may be the cause of a minor change in peak positions (if seen in comparison to pure $SnO_2$). Such a distortion is a sign that the lattice parameters have been successfully modified and doped. Additionally, the apparent broadening of the diffraction peaks indicates that the produced material is nanocrystalline and purifacation. Overall, as illustrated in Figure (3).

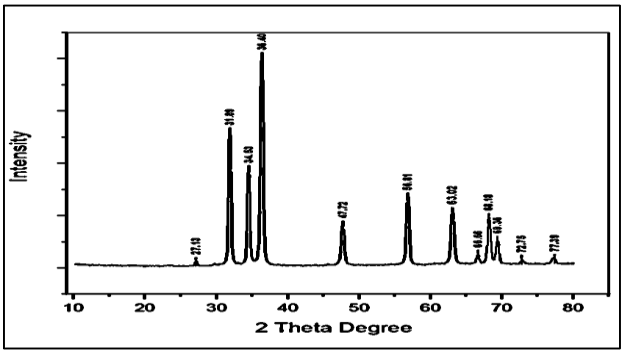



**Figure 3**: X-ray for nanoparticles compound synthesed cloved extract- Se/$SnO_2$

### 3.3. Effect of Dye Concentration on Photo-Oxidation

By doing a series of studies with concentrations ranging from 5 to 10 to 15 ppm, a constant intensity of 1.74 mW $cm^{-2}$, and a constant weight of 0.4 g, the impact of the initial dye concentration was investigated. In the presence of light and cinnamon extract- Se/$SnO_2$ acting as a catalyst at a concentration of 0.4 g per mL100 of the dye, Figure 4 shows the connection between absorbance and time. Over time, a decline in absorbance was noted (60). The following formula was used to get the nanosurface efficiency: Where Co is the initial dye concentration and Ct is the dye concentration following the test period (time t), the photocatalytic degradation efficiency (PDE%) is equal to:

$$(C0 - Ct) / C0 \times 100 \qquad (1)$$

When the concentration was 0.10 ppm, the efficiency was 100%. and 99.3% at 15 parts per million concentration, as shown in Figure 4.

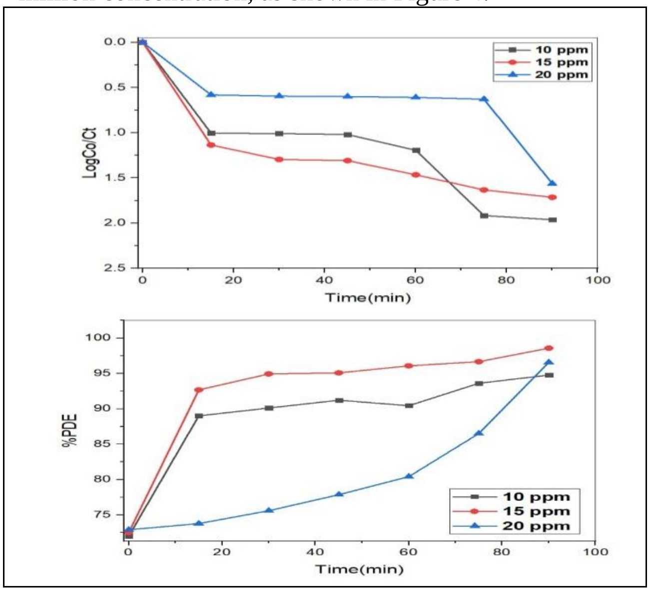



**Figure 4**: The relationship between absorbance and time in the presence of the catalyst (clove extract- Se/$SnO_2$) at different concentrations under the influence.

### 3.4. Effect of Weight on Photo-oxidation:

The effect of varying weights of Clove extract- Se/$SnO_2$ extract on the photo-oxidation of the dye in the presence of a catalyst. Different weights of Clove extract- Se/$SnO_2$ extract, ranging from 0.1 to 0.3 g, were used, along with a constant dye concentration (10 ppm), a constant intensity (1.74 mw $cm^{-2}$), and exposure to photocatalysis for 90 minutes. Figure (5) shows that the breakdown efficiency is highest when using a catalyst weight of approximately 0.4 g. This may be attributed to the fact that the light scattering required for the breakdown process is unsuitable at other concentrations. The efficiency was 94% at a weight of 0.2 g and 95% at a weight of 0.6 g. The effect of a photocatalyst concentration of 0.4 g for 90 minutes and a reaction temperature of 25°C on the photo-oxidation of the CR dye is shown in Figure 5. The efficiency ratio was 99.5%, and the results were discussed using a first-order pseudo-kinetic model.

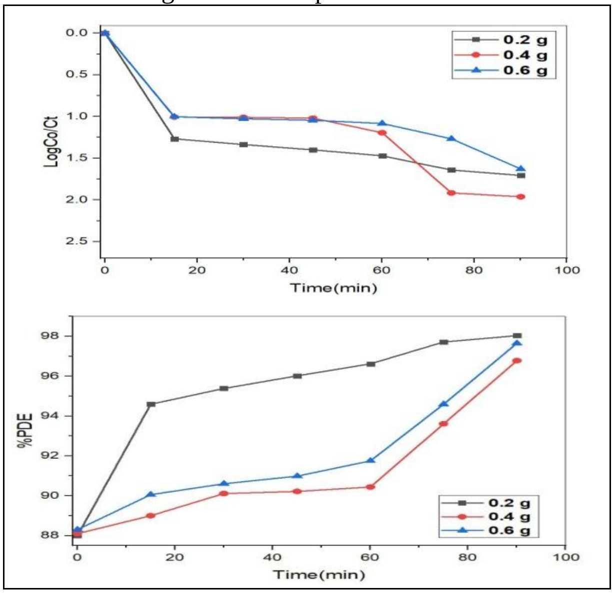



**Figure (5)**: The relationship between absorbance and time in the presence of the catalyst (Clove extract – Se/$SnO_2$) nanoparticles with weights of (0.2, 0.4, 0.6) gm under the influence of the photo catalytic process

### 3.5. The Effect of Solvent on Photo-Oxidation

Using 0.4 g, 10 ppm CR dye, 1.74 mW/cm², and a temperature of 298 K, Figure 6 illustrates the photolysis of Congo Red dye at different peroxide and methanol concentrations over 90 minutes. The kinetics of the reaction were comparable to those found in other studies. There is a limit to the concentration of $H_2O_2$ at which hydroxyl radicals are generated. Hydroxyl ions are consumed in other reactions instead of taking part in oxidation pathways. The rate of hydroxyl radical degradation is slowed by the $CH_3OH$ ion, which functions as a hole scavenger by reacting with the holes created by photosynthesis. In addition to producing free radicals, hydrogen peroxide can also operate as an electron acceptor, which facilitates charge separation. The following examples demonstrate hydroxyl radicals:

$$H_2O_2 + e^- \rightarrow OH^- + OH^- \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$H_2O_2 + O_2 \rightarrow OH^- + OH^- + O_2 \ldots\ldots\ldots\ldots (3)$$

Methanol is used extensively in industry as a solvent and as a raw material to make fuels, antifreeze, and formaldehyde. The targeted efficiency was 94.8% for methanol and 98.6% for peroxide.

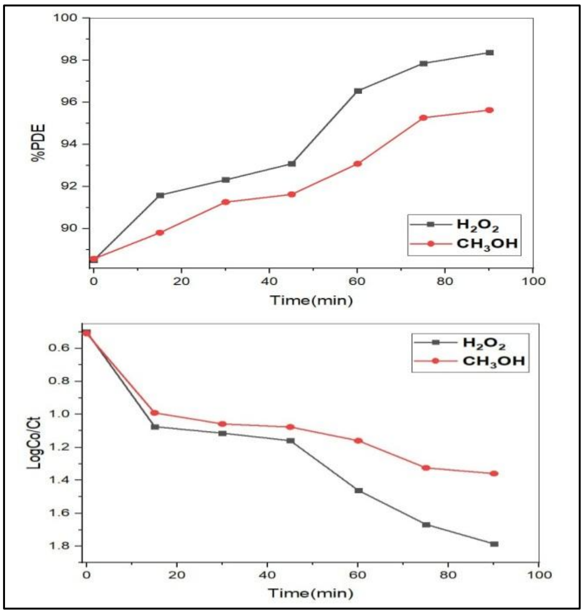



**Figure 6**: photocatalysis process affects the connection between absorbance and time in the presence of the catalyst (clove extract- Se/$SnO_2$ nanoparticles) and the solvent

**Examination of Recycling Uses (Removal of Pollutants):**

Because of their uses and possible hazards to aquatic life, dyes rank among the most important contaminants in water. It seems that it is required to assess the potential for recycling the adsorbent material, which is established by adsorption studies, in order to lower the cost of the adsorption process. Following the preparation of a 100 mL solution that contained distilled water, different concentrations (10,15,20 ppm) of saturated sorbent (0.4 g) clove extract- Se/$SnO_2$ was added. After 1.5 hours of contact, the particles of the regenerated sorbent were separated and allowed to dry overnight at 75°C. After four cycles of reuse, this photocatalyst likewise demonstrated good stability. Thus, it can be said that because of its great efficiency and inexpensive cost, the catalyst clove extract- Se/$SnO_2$ has a high swelling potential for use in wastewater decolorization. Clove extract- Se/$SnO_2$ is a nanocomposite that is recycled for the photolysis of G.R. dye. With an initial red dye concentration of 10 mg/L, a dose of 0.4 g/L, and a light intensity of 1.74 mW/cm2, the experimental efficiency study's findings demonstrated that in contrast to the normal (fresh) solution, which achieved 94% as illustrated in Figure (7), the hydrolysis efficiency during cycle (3) was 84%, 74%, and 67%.

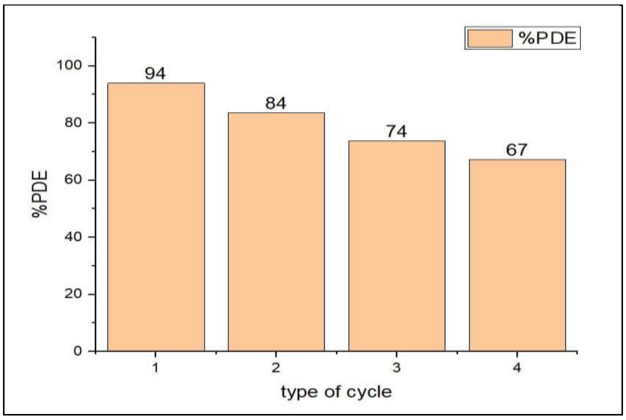



**Figure (7)**: Shows recycle a Nano composite prepared Clove Extract- Se/$SnO_2$ to break down G.R. dye.

## 4. CONCLUSION

An effective and eco-friendly approach was used to create green granular $SnO_2$ nanoparticles doped with selenium. The successful synthesis and production of nanoparticles with appropriate size and shape, good distribution, and decreased agglomeration were shown by characterization techniques (such as XRD and SEM). Clear, pure, and homogeneous crystals were also generated by the prepared nanocomposite. The application of clove extract enhanced the nanoparticles' surface and physical characteristics, which increased their efficacy in eliminating the environmental contaminant Congo Red. The produced nanoparticles were very effective at eliminating Congo Red from aqueous solutions. The initial dye concentration, contact time, and pH all had an impact on the removal efficiency. The findings show that photodegradation is a key component of the removal mechanism. The produced nanoparticles show promise as a cheap, eco-friendly, and an echonomical method of detoxifying water tainted with industrial dyes.

## REFERENCES

Abdul-Azeez Hatem Mohammed, Haneen A. Kh. Karaghool. (2024). Sustainable Adsorption of Congo Red Dye Using Organic Waste Materials as Green Adsorbents: A Mini-Review, Al-Rafidain Journal of Engineering Sciences Vol. 2, Issue 2: 78-86

Alamo-Nole, L.; Bailon-Ruiz, S.J. (2024). Photocatalytic Degradation of Methylene Blue by Surface-Modified SnO2/Se-Doped QDs. Micro, 4, 721–733.

Al-Rawashdeh, N. A. F., Allabadi, O., and Aljarrah, M. T. (2020). Photocatalytic activity of graphene oxide/zinc oxide nanocomposites with embedded metal nanoparticles for the degradation of organic dyes. ACS Omega, 5(43), 28046–28055. https://doi.org/10.1021/acsomega.0c03608

Ardila-Leal, L.D.; Poutou-Piñales, R.A.; Pedroza-Rodríguez, A.M.; Quevedo-Hidalgo, B.E. (2021). A Brief History of Colour, the Environmental Impact of Synthetic Dyes and Removal by Using Laccases. Molecules, 26, 381

Ashok Kumar, Utkarsh Dixit, Kaman Singh, Satya Prakash Gupta and Mirza S. Jamal Beg. (2021). Structure and Properties of Dyes and Pigments, DOI://dx.doi.org/10.5772/intechopen.97104

Aslan N. (2022). Synthesis and Characterization of ZnO@Fe3O4 Composite Nanostructures by Using Hydrothermal Synthesis Method. Türk Doğa ve Fen Dergisi.;11(1):95- 101.

Benkhaya, S.; M'rabet, S.; El Harfi. (2020). A. Classifications, properties, recent synthesis and applications of azo dyes. Heliyon, 6, e03271.

Bhavana Balachandran [a], P.C. Sabumon. (2025). A Comprehensive review on biodegradation of azo dye mixtures, metabolite profiling with health implications and removal strategies, *Journal of Hazardous Materials Advances Volume 19*, August, 100834, https://doi.org/10.1016/j.hazadv; 100834

Farhan, A., Zulfiqar, M., Samiah, Rashid, E. U., Nawaz, S., Iqbal, H. M. N., Jesionowski, T., Bilal, M., and Zdarta, J. (2023). Removal of toxic metals from water by nanocomposites through advanced remediation processes and photocatalytic oxidation. Current Pollution Reports, 9(3), 338–358. https://doi.org/10.1007/s40726-023-00253-y

Giˇcevi´c, A.; Hindija, L.; Karaˇci´c.(2019). A. Toxicity of Azo Dyes in Pharmaceutical Industry. In International Conference on Medical and Biological Engineering; Springer: Cham, Switzerland; Berlin/Heidelberg, Germany; pp. 581–587.

Haro-González JN, Castillo-Herrera GA, Martínez-Velázquez M,Espinosa-Andrews H. (2021). Clove Essential Oil (Syzygium aromaticumL. Myrtaceae): Extraction, Chemical Composition, Food Applications, and Essential Bioactivity for Human Health. Molecules.;26:6387.

Huang, Y.; Su, E.; Ren, J.; Qu, X. (2021). The recent biological applications of selenium-based nanomaterials. Nano Today, 38, 101205.

Ismail, M.; Akhtar, K.; Khan, M.I.; Kamal, T.; Khan, M.A.; Asiri, A.M.; Seo, J.; Khan, S.B.(2019). Pollution, toxicity and carcinogenicity of organic dyes and their catalytic bio-remediation. Curr. Pharm. Des., 25, 3645–3663.

Lekshmi, G.S.; Ramasamy, T.; Bazaka, O.; Levchenko, I.; Bazaka, K.; Govindan, R.; Mandhakini, M. (2022). Antioxidant, Anti-Bacterial, and Congo Red Dye Degradation Activity of AgxO-Decorated Mustard Oil-Derived rGO Nanocomposites. Molecules, 27, 5950.

Li, X.; Ge, W.; Wang, P.; Han, K.; Zhao, H.; Zhang, Q.; Diwu, H.; Liu, Z. (2023).Near-infrared enhanced SnO2/SnSe2 heterostructures for room-temperature NO2 detection: Experiments and DFT calculations. Sens. Actuators B Chem., 397, 134643.

Lynda Sabrina Ounaceura, Mabrouka Bouachaa, Oumaima Taguidaa, Nesrine Djabera, Mahfoud Messarahaand Amel Boumendjel. (2023). Chemical Composition, Antioxidant and Antimicrobial Activities of the Aqueous Extract of Syzygium aromaticum(Clove) from Indonesia, Uttar Pradesh Journal of ZoologyVolume 44, Issue 21, Page 178-191; Article no.UPJOZ.2887ISSN: 0256-971X (P).

Mahasin Ahmed Wadi. (2025).Evaluation of antibacterial activity and chemical analysis of clove aqueous extract (Syzygium aromaticum), Wadi BMC Complementary Medicine and Therapies) 25:146, https://doi.org/10.1186/s12906-023-04243-x

Malik S, Muhammad K, Waheed Y.(2023). Nanotechnology: A Revolution in Modern Industry. Molecules.; 28(2):661.

Maurice O.Iwunze.(2010). Determination of physico-chemical properties of Congo red in aqueous solution, PCAIJ, 5(2), [84-89], ISSN: 0974 – 7524.

Narendra Verma and Priyanka Gupta. (2025). Applications of Nanocomposites in Removal of Dyes from Wastewater: A Critical Review, RSYN Chem. Sci., 2(1), 7-22 | 7, DOI:10.70130/RCS.2025.0201002.

Omidvar, A., Jaleh, B., and Nasrollahzadeh, M. (2017). Preparation of the GO/Pd nanocomposite and its application for the degradation of organic dyes in water. J. Colloid Interface Sci, 496, 44–50. https://doi.org/10.1016/j.jcis.2017.01.113

Palani, G., Trilaksana, H., Sujatha, R. M., Kannan, K., Rajendran, S., Korniejenko, K., Nykiel, M., and Uthayakumar, M. (2023). Silver nanoparticles for wastewater management. Molecules, 28(8), Article 3520. https://doi.org/10.3390/molecules28083520

Pattnaik, A., Sahu, J. N., Poonia, A. K., and Ghosh, P. (2023). Current perspective of nano-engineered metal oxide based photocatalysts in advanced oxidation processes for degradation of organic pollutants in wastewater. Chemical Engineering Research and Design, 190, 667-686.

Rustembekkyzy, K., Sabyr, M., Kanafin, Y. N., Khamkhash, L., and Atabaev, T. Sh. (2024). Microwave-assisted synthesis of ZnO structures for effective degradation of methylene blue dye under solar light illumination. RSC Advances, 14(26), 16293–16299. https://doi.org/10.1039/D4RA02451F

Sharf Ilahi Siddiqui, Esam S. Allehyani, Sami A. Al-Harbi, Ziaul Hasan, May Abdullah Abomuti 5, Hament Kumar Rajor 1,and Seungdae Oh. (2023). Investigation of Congo Red Toxicity towards Different Living Organisms: A Review, Processes, 11, doi.org/10.3390/pr11030807

Stefania Mura,Pietro Rassu, Federico Fiori,Gabriele Masia, Sebastiano Garroni, Salvatore Marceddu, Ylenia Spissu, Luca Malfatti, Plinio Innocenzi, (2025), Boosting Visible Light Photocatalysis: Se Rods Decorated with $SnO_2$ Nanoparticles, Materials, 18(18),4300; doi.org/10.3390/ma18184300

Tara, N.; Siddiqui, S.I.; Rathi, G.; Chaudhry, S.A.; Inamuddin; Asiri, A.M. (2020).Nano-engineered Adsorbent for the Removal of Dyes fromWater: A Review. Curr. Anal. Chem., 16, 14–40.

Yates, E.; Yates. (2016). A. Johann Peter Griess FRS (1829-88): Victorian brewer and synthetic dye chemist. Notes Rec. R. Soc. Lond.70, 65–81.

Zainab Abas Abdul-Zahra 1, Ala'a H. Hussain 1, Inam Joudah Radhi, and Radhiah Najm Abd. (2025). Synthesis and Characterization of Silver Nanoparticles from Triticum Aestivum L. Extract, J Nanostruct 15(4): 1671-1677.