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Microwave-assisted Synthesis of Cobalt Oxide Nanoparticles with *Carica papaya* Leaf Extract and their Catalytic Activities

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The Physico-chemical and optical characteristics of cobalt oxide nanoparticles (CoONPs) have attracted interest in their creation over the past few years. In the current study, microwave irradiation was used to induce the production of CoONPs from papaya leaf extract. Papaya leaf extract was prepared by pulverizing and drying the plant's leaves. The extract was then heated to create an aqueous extract, which was purified and saved for analysis. Cobalt nitrate was added to the extract, and a dark brown color was obtained. CoO NPs were used as a catalyst in the

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reduction of MB and CR, with a mixture of MB solution and NaBH4 in DD water. The catalytic reduction of 4-NP was also tested using CoO NPs. The experimental procedures for characterizing *Carica papaya* leaf extract CoO NPs include UV-Vis spectra, TEM, and FTIR for analyzing nanomaterial morphology, size, and chemical composition. X-ray Diffraction (XRD) spectroscopy provides information about the crystalline structure, which is crucial for understanding nanomaterial behavior and potential applications in fields like medicine, electronics, and materials science. These methods are critical for understanding nanomaterial behavior and potential applications in various fields.

Keywords: Carica papaya leaf extract; CoONPs; FTIR; TEM; XRD; catalytic activities.

1. INTRODUCTION

Despite the fact that contemporary enterprises have expanded rapidly over the past few decades, environmental degradation has so far become a severe threat to human well-being on a global scale. The contamination of water bodies caused by the discharge of untreated water containing inorganic and organic species has received a lot of attention recently among the numerous types of environmental pollution [1]. Aquatic habitats are thought to suffer severe harm from the unregulated release of azo dyes, which are frequently employed in the leather, textile, plastic, cosmetics, ink, paper, and food sectors [2]. Organic dyes can last for a long time in the environment because of their photo- and thermal stability, as well as their capacity to withstand biodegradation [3,4,5,6]. According to reports, the presence and persistence of these oxygen-sequestering species in water systems reduces light penetration and prevents aquatic vegetation from photo synthesizing. Therefore, before industrial effluents containing hazardous organic dyes may be properly discharged to the environment, they must be broken down and decolored. The U.S. EPA classifies phenolic chemicals, including the well-known nitrophenol derivatives, along with organic azo dyes as priority pollutants that have a direct impact on human health and the environment [7].

Up to date, a wide range of technologies have been created to remove colorants from waste water, including physical absorption, chemical oxidation, chemical degradation, membrane filtration, biological degradation, and membrane filtering [8]. Due to their exceptional catalytic activity and effective color removal, metal oxide nanoparticles have received the most interest when it comes to the catalytic degradation of organic dyes [9]. However, a number of obstacles prevent the practical application of these nanoparticle catalysts. For instance, recycling these colloidal nanoparticles in an aqueous solution for environmentally friendly purposes is challenging [10]. Additionally, the nanoparticles tend to agglomerate due to their high surface energy and huge surface area. These days, a variety of materials, including graphene, Fe_3O_4 microspheres, zeolites, polymeric microspheres, etc., have been used as supports [11]. The nanoparticles, which have strong antibacterial properties, are valuable in the pharmaceutical industry due to their antibacterial properties [12].

Due to their unique characteristics, cobaltoxide nanoparticles (CoONPs) have received a lot of attention. Gas sensors, catalysis, batteries, high temperature superconductors, and solar energy conversion devices are just a few of the uses for CoONPs. CoONPs are much more durable, stable, and long-lasting than organic anti-microbial compounds [13]. CoONPs can be made using a variety of physical and chemical processes. However, these techniques have limitations, including the use of hazardous reducing agents, organic solvents, and high temperatures and pressures [14]. The green synthesis of nanoparticles using plant extracts, however, holds great promise for increasing nanoparticle production without the use of hazardous or expensive chemicals [15]. Therefore, it is necessary to create and apply safe synthetic procedures that are economical, efficient, nontoxic, and friendly to the environment. Recently, it was reported that Populus ciliata leaf extract was used in the manufacture of CoONPs [16].

In the present study, we are reporting the synthesis of CoONPs using papaya leaf extract. Papaya belongs to the family Caricaceae and is a medicinal plant [17]. Numerous active substances, including papain, chymopapain, cyanogenic glucosides, cystatin, -tocopherol, ascorbic acid, flavonoids, and gluco-sinolates, have been found to be present in papaya leaves [18]. Several illnesses, including amenorrhea, general debility, constipation, corns, cutaneous tubercles, warts, sinusitis, eczema, glandular tumors, blood pressure, diabetes, malaria, intestinal worms, and syphilis are treated with papaya bark, leaves, and fruits [19].

In the current study, a microwave irradiation technique has been developed to produce CoO NPs using papaya leaf extract, a cheap and abundant natural resource and Synthesized CoO NPs have been characterized using UV-Vis, FTIR, XRD, and TEM. The resulting CoO NPs are spherical in shape and highly crystalline. When containing NaBH4, these capped CoO NPs are effective in reducing 4-NP, MB, and CR compounds. This innovative catalyst is expected to be widely used in organic catalysis, making it suitable for treating industrial effluents containing toxic contaminants.

2. MATERIALS AND METHODS

2.1 Chemicals and Reagents

Cobalt nitrate hexahydrate ($Co(NO_3)_2.6H_2O$), (99%), was bought from Sigma Aldrich, India. The 4-NP, MB, and CR dyes were procured from Merck, India The other substances employed in this experiment were all analytic reagent grade and didn't require any additional purification. All of the investigations were conducted using double distilled (DD) water.

2.2 Preparation of Papaya Leaf Extract

The papaya plant's fresh leaves were plucked, finely chopped, and allowed to dry in the shade. It was pulverized and used for further research after drying. 2 grams of leaf extract powder were added to a 100 ml Erlenmeyer flask containing double-distilled water and heated for 30 minutes at 55 °C to create the aqueous extract. The resulting extract was purified with Whatman No. 1 filter paper, and the filtrate was saved for later analysis.

2.3 Synthesis of CoONPs

A source of cobalt, 50 ml of cobalt nitrate with a 2 mM concentration, was added dropwise into 15 ml of extract, which was then continuously stirred at room temperature for 30 min. A microwave irradiation at 450W power for 4 minutes followed, and the resulting dark brown color indicated that CoONPs were successfully synthesized [13].

2.4 Catalytic Reduction of MB and CR

In the presence of $NaBH_4$, CoONPs were used as a catalyst in the reduction of MB and CR. In a typical procedure, 2.5 mL of 1 mM MB solution was mixed with 1.5 mL of 10 mM $NaBH_4$ in DD water and stirred for 5 minutes. In a cuvette, 3 mL of this reaction mixture was added to 10 mg of CoONPs, and UV-Vis spectra were recorded at various time intervals. In addition, CR dye was used in the same way [1].

2.5 Catalytic Reduction of 4-NP

CoONPs were tested for their catalytic activity by reducing 4-NP. In a typical experiment, 1.6 ml of 4-NP (0.2M) and 1 ml of $NaBH_4$ (2 mM) were combined in an aqueous solution and placed in a quartz cuvette for the reaction. The aforementioned combination received 10 mg of CoONPs, and the reaction was watched by capturing the UV-Vis spectra at 1-minute intervals [2].

2.6 Characterization of *Carica papaya* Leaf Extract CoONPs

The experimental procedures for characterizing *Carica papaya* leaf extract CoO NPs include a number of sophisticated techniques for measuring their unique characteristics. UV-Vis spectra (UV-Vis, Shimadzu, spectrum one), Transmission Electron Microscopy (TEM, JEOL), and Fourier Transform Infrared Spectroscopy (FTIR, Agilent) are common techniques for analyzing nanomaterial morphology, size, and chemical composition. Additionally, X-ray Diffraction (XRD, Rigaku) spectroscopy provides information about the crystalline structure. These methods are critical for understanding nanomaterial behavior and potential applications in a range of fields, such as medicine, electronics, and materials science.

3. RESULTS AND DISCUSSION

3.1 UV-Visible spectra

UV-visible spectra were used to examine the progression of the reaction between the components in the extract and the cobalt ions. The UV-Visible absorption spectrum of synthesized CoONPs was showed in Fig. 1., the peak appeared at 504 nm. This absorption band is the source of the CoONPs plasma resonance absorption. The continuous oscillation of the electrons in the conduction band brought on by the interaction of the electro-magnetic field is the cause of light absorption by nanoparticles. The surface plasmon absorption band that the CoONPs display in the range of 350–550 nm is their distinctive property [20]. The extracts function as a reducing-cum-surface capping agent, which is responsible for the synthesis of CoONPs.

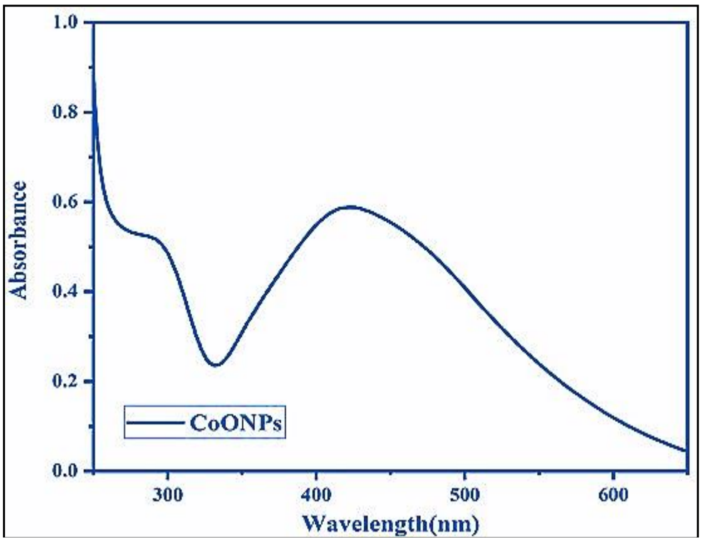

Fig. 1. UV-Vis spectra of CoONPs prepared using papaya leaf extract

3.2 FTIR

The potential biomolecules responsible for CoONPs stabilization and reduction were determined using FTIR measurements. The FTIR spectrum of the extract mediated synthesized CoONPs shown in Fig. 2. The presence of phenol functionalities in papaya leaf extract is revealed by FT-IR analysis. The phenol O-H stretching groups are represented as absorption peaks in the spectrum at about 3343 cm^{-1}, 1740 cm^{-1} peak is corresponds to carbonyl group, 1608 cm^{-1} from the resonance groups of the aromatic C=C, and 2917 cm^{-1} from the C-H aliphatic. C-H deformations and in-plane O-H bending was assigned to absorptions at 1352 cm^{-1}. Peaks from 1022 cm^{-1} were found to correlate to C-O-C glycosidic linkage vibrations as well as secondary alcohols and phenols C-O stretching and O-H deformation vibrations. As a result of the characteristic peaks observed in the FTIR spectrum of the as-synthesized CoONPs, flavonoids, steroids, saponins, tannins, alkaloids, phenols, sugar, saccharides, and proteins were also found in the papaya extract. This confirms that these chemicals can also act as reducing agents as well as cappers [21].

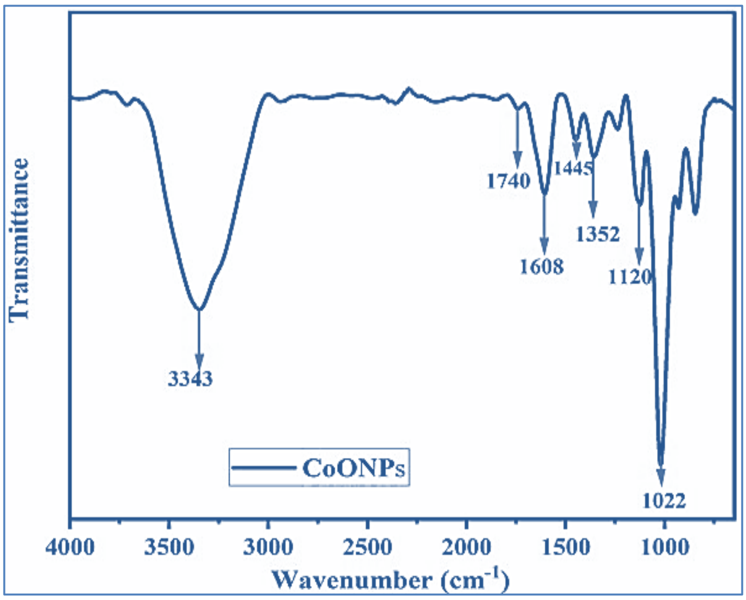

Fig. 2. FTIR spectra of synthesized CoONPs

3.3 XRD

The XRD analysis was evaluated the phase and crystal structure of the synthesized CoONPs. The characteristic peaks in the green synthesized CoONPs XRD pattern at 31.66, 36.45, 45.48, 56.53, 61.45, 66.17 and 75.25, which were corresponds to 220, 311, 400, 422, 511, 440 and 533 respectively **(**Fig. 3). The International Centre for Diffraction Data card no. 42-1467 indicates the formation of the crystalline phase of CoONPs [22]. CoONPs produced by various plant extracts have been reported to have similar XRD patterns.

3.4 TEM

The TEM examination was utilized to know the size, shape, morphology of CoONPs were and TEM image of CoONPs are displayed in Fig. 4 (a). This makes it clear that the majority of the nanoparticles are spherical in shape and evenly distributed. The particle size distribution histogram makes it evident that the size of the generated nanoparticle is between 3 and 20 nm (Fig. 4b). It is discovered that the average particle size is 8±2 nm.

3.5 Catalytic Activity of CoONPs

Numerous studies have examined the catalytic activity of CoONPs in the reduction of various dyes, including 4-NP, MB, and CR, and biosynthesized CoONPs have been shown to be a very effective catalytic element due to their simple, affordable, and environmentally friendly synthesis process. The reducing agent $NaBH_4$ was frequently used as a model reaction while examining these nanoparticles' catalytic potential.

3.6 Catalytic Reduction of MB

In the case of MB, it is a dye that is frequently used in biology and chemistry, can build up, and may be harmful to the environment. When reduced, MB loses its blue and turns into the colorless (leuco methylene blue). Fig. 5a depicts the UV-Vis absorption spectra of the reduction of MB by $NaBH_4$ in the absence of the catalyst CoONPs. Even after 30 minutes, the magnitude of the MB absorption peak decreases slightly when $NaBH_4$ is present in Fig. 5a. These findings suggest that in the absence of CoONPs, the reduction reaction was slow. As can be seen in Fig. 5b, the UV-Vis spectrum of the $NaBH_4$ reduction of MB in the presence of CoONPs catalysts was obtained [23]. Due to $\pi \rightarrow \pi^*$ and $n \rightarrow \pi^*$ transitions, MB normally exhibits an absorption maximum band at about 664 nm in aqueous solution. But when CoONPs were added to the aforementioned reaction mixture, MB was completely reduced in just 7min. According to Fig. 5b, the MB has reduced as seen by the continuous decrease in MB's absorption peak strength at 664 nm with increasing time. Furthermore, the procedure never reached its peak appearance. At 10 mg of CoONPs and room temperature, the reduction of MB follows a pseudo-first order kinetics, as shown by the linear relationship between $\ln(A_t/A_0)$ vs reaction time (Fig. 5c) [1]. The rate constant was determined to be 0.332 min^{-1}.

3.7 Catalytic Reduction of CR

Utilizing UV-Vis spectroscopy, these reduction reactions were tracked. CR exhibits an absorbance peak at 350 nm and 498 nm in aqueous solution [24]. The UV-Vis spectra of CR with $NaBH_4$ in the absence of CoONPs were captured over the course of 30 minutes at room temperature and are shown in Fig. 6a. Fig. 6a depicts a little tendency toward decreasing absorption peak intensity, which suggests a steady reduction in CR [25]. When CoONPs were introduced to the combination of CR and $NaBH_4$, the amount of CR that was absorbing quickly decreased. Within 5minutes, the reduction reaction was finished. The constant decline of the CR absorption peak at 493 nm over time that can be seen in Fig. 6b indicates that the dye has deteriorated gradually. Furthermore, during the process, there was no peak visible [26]. It was discovered that the decrease of dyes follows pseudo-firs-order kinetics, given that the concentration of $NaBH_4$ was substantially greater than that of dye (Fig. 6c), indicating that the reduction of dyes follows pseudo-firs-order kinetics. The rate constant was found to be 0.443 min^{-1}.

3.8 Catalytic Reduction of 4-NP

We studied the catalytic reduction of 4-NP using CoONPs as the catalyst and $NaBH_4$ as the reducing agent. 4-NP is well-known for its many beneficial uses, including the manufacture of dyes, pharmaceuticals, photo-graphic developers, agrochemicals, and anticorrosion. The maximum peak of aqueous 4-NP is visible at 317 nm [27]. When $NaBH_4$ was added to 4-NP, the peak was moved to 400 nm, and an intense yellow color was produced as a result of the creation of para nitrophenolate ion. The reaction cannot occur without a catalyst, and the peak persisted for several hours (Fig. 7a). However, the peak at 400 nm declines with the addition of produced CoONPs, and a new peak at 297 nm related to the synthesis of 4-AP appears instead [28]. After 7 min the peak intensity at 400 nm related to 4-NP almost diminished, indicating that the reduction of 4-NP was closely completed. The presence of CoONPs in the reaction supported the transfer of electrons from $NaBH_4$ to the 4-NP nitro group and its reduction to 4-AP. UV-Vis spectroscopy was used to qualitatively monitor this reaction, as illustrated in Fig. 7b. This research demonstrated the produced CoONPs catalytic activity for 4-NP reduction when distributed in papaya leaf extract. The pseudo first order kinetics equation was used to determine the rate constant of this catalytic reduction reaction with respect to 4-NP concentration. Because there was a higher initial concentration of $NaBH_4$ than 4-NP, the rate of reduction was independent of $NaBH_4$ concentration [29]. The slope of the plot of $\ln(A_t/A_o)$ over time (Fig. 7c) was used to calculate the rate constant and was found to be 0.330 min^{-1}.

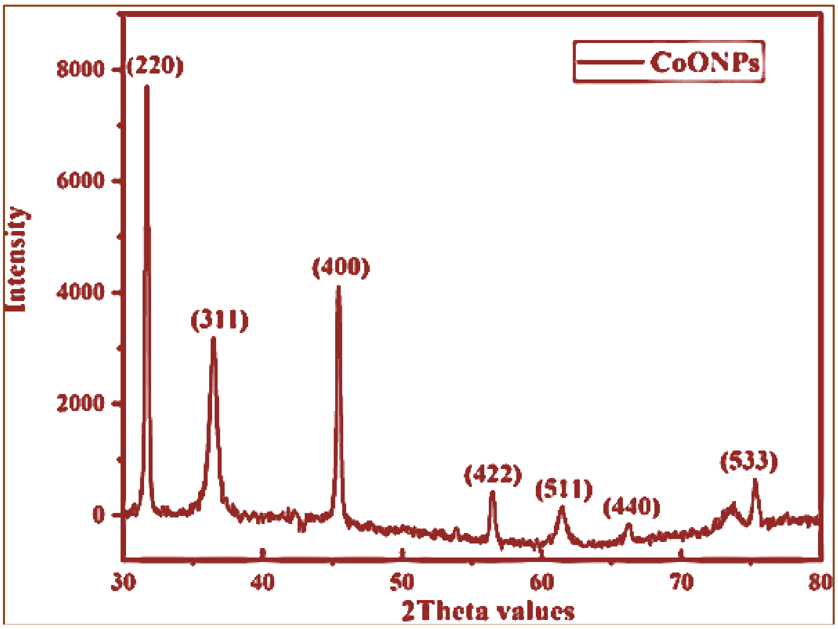

Fig. 3. XRD pattern of synthesized CoONPs

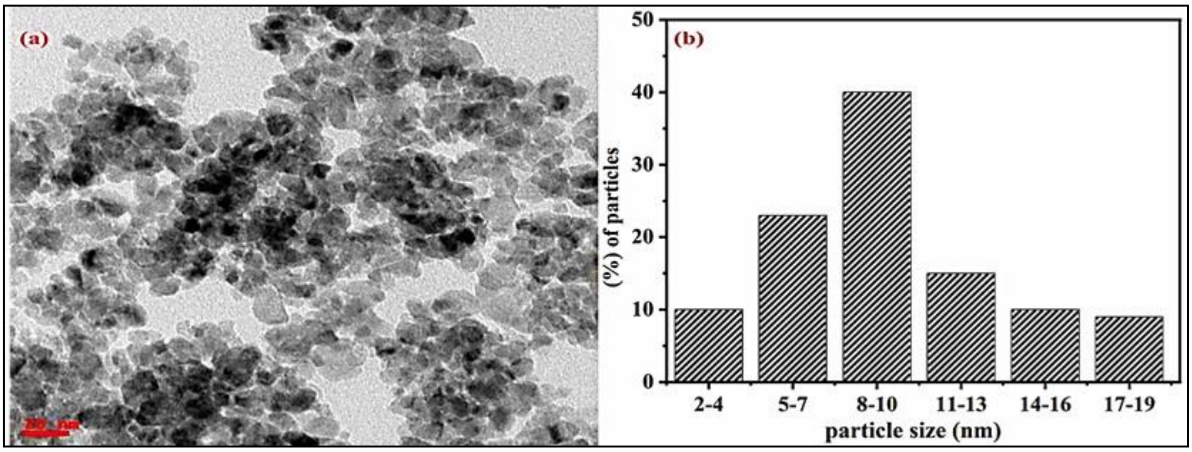

Fig. 4(a). TEM image of synthesized CoONPs and (b) particle size distribution of CoONPs

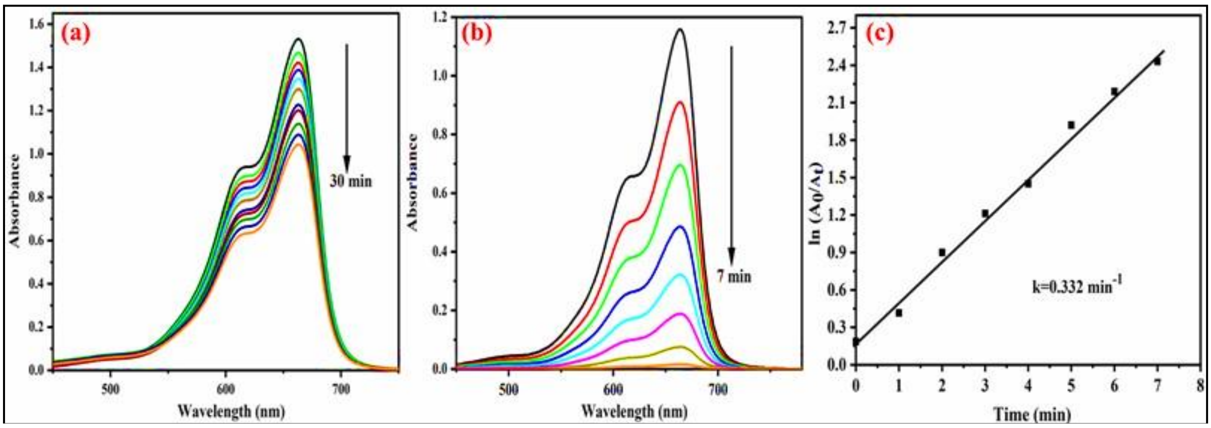

Fig. 5 (a). UV-Vis spectrum of reduction of MB by $NaBH_4$ in the absence of CoONPs for a period of 30 min at room temperature. (b) UV-Vis spectrum for the catalytic reduction of MB by $NaBH_4$ in presence of CoONPs. (c) Plot of ln(A_0/A_t) against time.

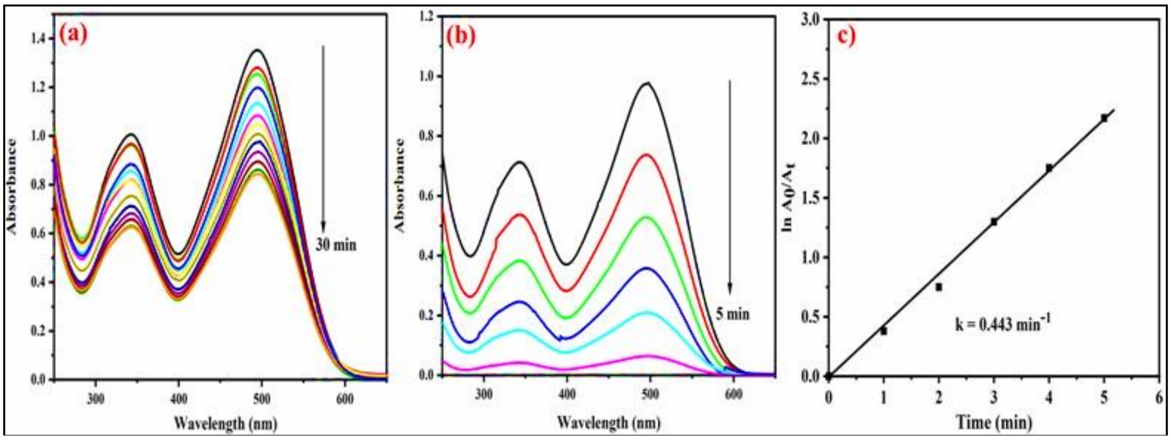

Fig. 6 (a). UV-Vis spectrum of reduction of CR by $NaBH_4$ in the absence of CoONPs for a period of 30 min at room temperature. (b) UV-Vis spectrum for the catalytic reduction of MB by $NaBH_4$ in presence of CoONPs. (c) Plot of ln(A_0/A_t) against time

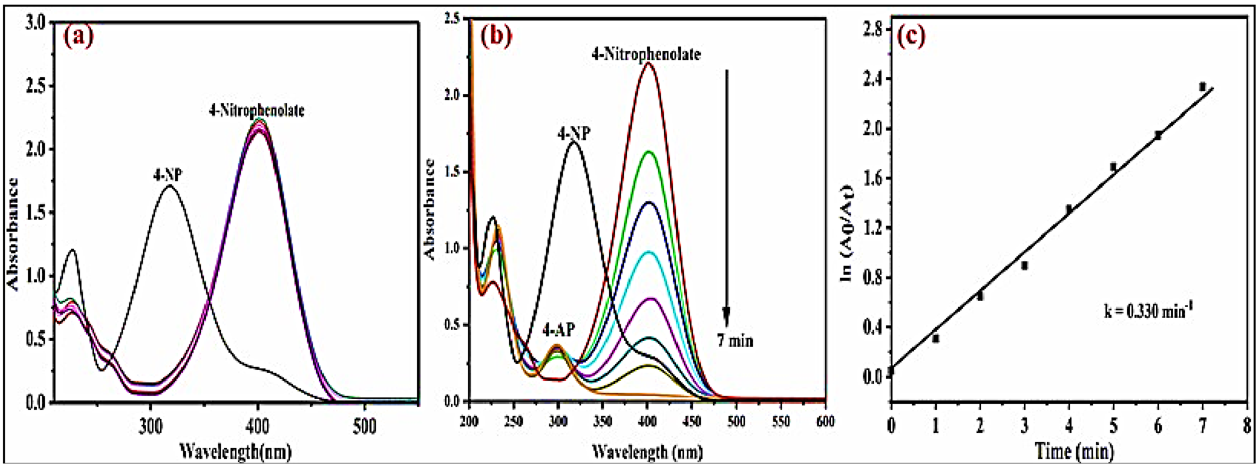

Fig. 7 (a) UV−vis spectra of 4-nitrophenol and 4-nitrophenol with $NaBH_4$ without addition of any catalyst (b)4-nitrophenol with $NaBH_4$ in the presence of CoONPs as catalyst (c) and plot of ln(A_0/A_t) against the reaction time

4. CONCLUSIONS

In conclusion, we have effectively established an environmentally friendly microwave irradiation technique for producing CoONPs by reducing $(Co(NO_3)_2.6H_2O$ using papaya leaf extract, a cheap and plentiful natural resource. Papaya leaf extract served as a stabilizing and capping ingredient in this process. The majority of the CoONPs morphology was discovered to be spherical in shape. XRD analysis has verified the creation of extremely crystalline. In the presence of $NaBH_4$, capped CoONPs made from papaya leaf extract were found to be effective as catalysts for the reduction of 4-NP, MB, and CR compounds. It is envisaged that the innovative catalyst will find widespread practical use in the field of organic catalysis. Hence, papaya leaf extract-capped CoONPs are effective catalysts for the treatment of industrial effluents containing toxic contaminants.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (Chat GPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Ganapuram BR, Alle M, Dadigala R, Dasari A, Maragoni V, Guttena V. Catalytic reduction of methylene blue and Congo red dyes using green synthesized gold nanoparticles capped by salmalia malabarica gum. International Nano Letters. 2015;5:215–222. Available:https://doi.org/10.1007/s40089-015-0158-3.
2. Reddy GB, Madhusudhan A, Ramakrishna D, Ayodhya D, Venkatesham M, Veerabhadram G. Green chemistry approach for the synthesis of gold nanoparticles with gum kondagogu: characterization, catalytic and antibacterial activity. Journal of Nanostructure in Chemistry. 2015;5:185–193. Available: https://doi.org/10.1007/s40097-015-0149-y.
3. Vidhu VK, Philip D. Catalytic degradation of organic dyes using biosynthesized silver nanoparticles. Micron. 2014;56:54–62. Available:https://doi.org/10.1016/j.micron.2013.10.006.
4. Kobir Md Mahmudul, Sumaya Tabassum, Shanawaz Ahmed, Sumaiya Islam Sadia, Md Ashraful Alam. Crystallographic benchmarking on diffraction pattern profiling of polymorphs-TiO2 by WPPF for Pigment and Acrylic Paint”. Archives of Current Research International 2024; 24(1):62-70. Available:https://doi.org/10.9734/acri/2024/v24i1623.
5. Hasanpoor M, Aliofkhazraei M, Delavari HJ. Microwave-assisted synthesis of zinc oxide nanoparticles. Procedia Materials Science. 2015 Jan 1;11:320-5.
6. Bizani E, Fytianos K, Poulios I, Tsiridis V. Photocatalytic decolorization and degradation of dye solutions and wastewaters in the presence of titanium dioxide. Journal of Hazardous materials. 2006 Aug 10;136(1):85-94.
7. Kadir AA, Mohajerani A. Possible utilization of cigarette butts in light- weight fired clay bricks. International Journal of Environmental, Ecological, Geological and Minning Engineering. 2008;2:1–11.
8. Bindhu MR, Umadevi M, Esmail GA, Al-Dhabi NA, Arasu MV. Green synthesis and characterization of silver nanoparticles from Moringa oleifera flower and assessment of antimicrobial and sensing properties. Journal of Photochemistry and Photobiology B: Biology. 2020;205: 111836. Available:https://doi.org/10.1016/j.jphotobiol.2020.111836.
9. Ismail M, Khan MI, Khan SB, Akhtar K, Khan MA, Asiri AM. Catalytic reduction of picric acid, nitrophenols and organic azo dyes via green synthesized plant supported Ag nanoparticles. Journal of Molecular Liquids. 2018;268:87–101. Available:https://doi.org/10.1016/j.molliq.2018.07.030.
10. Ananda AP, Krishnamurthy NB, Savitha KR, Nagendra BS. Biogenic synthesis of silver nanoparticles using Priva cordifolia leaf extract (PC@AgNPs) a potent antioxidant, antibacterial and catalytic activity. SN Applied Sciences. 2019;1. Available: https://doi.org/10.1007/s42452-019-0818-4.

11. Nasrollahzadeh M, Sajjadi M, Iravani S, Varma RS. Starch, cellulose, pectin, gum, alginate, chitin and chitosan derived (nano)materials for sustainable water treatment: A review. Carbohydrate Polymers. 2021;251:116986. Available:https://doi.org/10.1016/j.carbpol.2020.116986.
12. Elias Takele Assefa, Gemechu Shumi, Kemal Mohammed Gendo, Girmaye Kenasa, Nebi Roba, Review on green synthesis, characterization, and antibacterial activity of CuO nanoparticles using biomolecules of plant extract. Results in Chemistry. 2024;8:1-8. Available:https://doi.org/10.1016/j.rechem.2024.101606.
13. Onwudiwe DC, Ravele MP, Elemike EE. Eco-friendly synthesis, structural properties and morphology of cobalt hydroxide and cobalt oxide nanoparticles using extract of Litchi chinensis. Nano-Structures and Nano-Objects. 2020;23:100470. Available:https://doi.org/10.1016/j.nanoso.2020.100470.
14. Kgosiemang IK, Lefojane R, Direko P, Madlanga Z, Mashele S, Sekhoacha M. Green synthesis of magnesium and cobalt oxide nanoparticles using Euphorbia tirucalli: Characterization and potential application for breast cancer inhibition. Inorganic and Nano-Metal Chemistry. 2020;50:1070–1080. Available:https://doi.org/10.1080/24701556.2020.1735422.
15. Mohammadi SZ, Lashkari B, Khosravan A. Green synthesis of Co3O4 nanoparticles by using walnut green skin extract as a reducing agent by using response surface methodology. Surfaces and Interfaces. 2021;23:100970. Available:https://doi.org/10.1016/j.surfin.2021.100970.
16. Hafeez M, Shaheen R, Akram B, Zain-Ul-Abdin S, Haq S, Mahsud S, Ali Khan RT. Green synthesis of cobalt oxide nanoparticles for potential biological applications. Materials Research Express. 2020;7. Available:https://doi.org/10.1088/2053-1591/ab70dd.
17. Sunkari S, Gangapuram BR, Dadigala R, Bandi R, Alle M, Guttena V. Microwave-irradiated green synthesis of gold nanoparticles for catalytic and anti-bacterial activity. Journal of Analytical Science and Technology. 2017;8:1–9. Available:https://doi.org/10.1186/s40543-017-0121-1.
18. Sankar R, Manikandan P, Malarvizhi V, Fathima T, Shivashangari KS, Ravikumar V. Green synthesis of colloidal copper oxide nanoparticles using *Carica papaya* and its application in photocatalytic dye degradation. Spectrochimica Acta - Part A: Molecular and Biomolecular Spectroscopy. 2014;121:746–750. Available:https://doi.org/10.1016/j.saa.2013.12.020.
19. Singh PDL, Thakur A, Kumar P. Green synthesis of glowing carbon dots from *Carica papaya* waste pulp and their application as a label-freechemo probe for chromium detection in water. Sensors and Actuators, B: Chemical. 2019;283:363–372. Available:https://doi.org/10.1016/j.snb.2018.12.027.
20. Bibi I, Nazar N, Iqbal M, Kamal S, Nawaz H, Nouren S, Safa Y, Jilani K, Sultan M, Ata S, Rehman F, Abbas M. Green and eco-friendly synthesis of cobalt-oxide nanoparticle: Characterization and photo-catalytic activity. Advanced Powder Technology. 2017;28: 2035–2043. Available:https://doi.org/10.1016/j.apt.2017.05.008.
21. Haq S, Abbasi F, Ben Ali M, Hedfi A, Mezni A, Rehman W, Waseem M, Khan AR, Shaheen H. Green synthesis of cobalt oxide nanoparticles and the effect of annealing temperature on their physiochemical and biological properties. Materials Research Express. 2021;8. Available:https://doi.org/10.1088/2053-1591/ac1187.
22. Ajarem JS, Maodaa SN, Allam AA, Taher MM, Khalaf M. Benign synthesis of cobalt oxide nanoparticles containing red algae extract: Antioxidant, antimicrobial, anticancer, and anticoagulant activity. Journal of Cluster Science. 2022;33:717–728. Available:https://doi.org/10.1007/s10876-021-02004-9.
23. Dewi NOM, Yulizar Y, Bagus Apriandanu DO. Green synthesis of Co3O4 nanoparticles using *Euphorbia heterophylla* L. leaves extract: Characterization and photocatalytic activity. IOP Conference Series: Materials Science and Engineering. 2019;509. *Euphorbia heterophylla.*

Available:https://doi.org/10.1088/1757-899X/509/1/012105.

24. Atkin P, Daeneke T, Wang Y, Carey BJ, Berean KJ, Clark RM, Ou JZ, Trinchi A, Cole IS, Kalantar-Zadeh K. 2D WS2/carbon dot hybrids with enhanced photocatalytic activity. Journal of Materials Chemistry A. 2016;4:13563–13571. *Euphorbia heterophylla.* Available:https://doi.org/10.1039/c6ta06415a.
25. Seku K, Gangapuram BR, Pejjai B, Hussain M, Hussaini SS, Golla N, Kadimpati KK. Eco-friendly synthesis of gold nanoparticles using carboxymethylated gum *Cochlospermum gossypium* (CMGK) and their catalytic and antibacterial applications. Chemical Papers. 2019;73:1695–1704. Available:https://doi.org/10.1007/s11696-019-00722-z.
26. Pandey S, Do JY, Kim J, Kang M. Fast and highly efficient catalytic degradation of dyes using κ-carrageenan stabilized silver nanoparticles nanocatalyst, Elsevier Ltd.; 2020. Available:https://doi.org/10.1016/j.carbpol. 2019.115597.
27. Sun X, He J, Meng Y, Zhang L, Zhang S, Ma X, Dey S, Zhao J, Lei Y. Microwave-assisted ultrafast and facile synthesis of fluorescent carbon nanoparticles from a single precursor: Preparation, characterization and their application for the highly selective detection of explosive picric acid. Journal of Materials Chemistry A. 2016;4:4161–4171. Available:https://doi.org/10.1039/c5ta10027e.
28. Murali I, Krishna G, Bhagavanth Reddy, Veerabhadram G, Madhusudhan A. Eco-friendly green synthesis of silver nanoparticles using salmalia malabarica: synthesis, characterization, antimicrobial, and catalytic activity studies. Applied Nanoscience (Switzerland). 2016;6:681–689. Available:https://doi.org/10.1007/s13204-015-0479-6.
29. Bhagavanth RR, Dadigala R, Bandi R, Seku K, Koteswararao D, Mangatayaru GK, Shalan AE. Microwave-assisted preparation of a silver nanoparticles/N-doped carbon dots nanocomposite and its application for catalytic reduction of rhodamine B, methyl red and 4-nitrophenol dyes. RSC Advances. 2021;11:5139–5148. Available:https://doi.org/10.1039/d0ra10679h.

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