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Irvingia Gabonensis Mediated Green Copper Nanoparticles Synthesis For Corrosion Control On Mild Steel In Seawater.

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***Abstract**—Green nanoparticles have evolved as a sustainable and eco-friendly alternative to typical conventional methods. This study presents research on the synthesis of plant extract nanoparticles using Irvingia gabonensis leaves extract and Copper(II)nitrate as the precursor metallic salt to synthesize nanoparticles for corrosion inhibition on mild steel in seawater. The Irvingia gabonensis plant extract was characterized and found to contain alkaloids, tannins, Saponins, terpenoids and Anthraquinone glycosides. Synthesized nanoparticles were characterized by visual observation, Uv-Visible spectroscopy, FTIR, SEM, EDX for estimation of elemental composition and X-ray diffraction for estimating size of nanoparticles together with Scherer's equation. Color change of extract solution from leafy green to dark brown minutes after formation was the first indicator of nanoparticles formation. FTIR showed the presence of alcohol and phenolic groups at 3276.3 cm^{-1}, single bonds alkanes and aldehydes at 2922.2 cm^{-1} and 2855.1 cm^{-1}. Alkyls and Nitriles at a band peak of 2172.1cm^{-1} suggests the presence of triple bond groups. SEM micrographs showed irregular shaped nanoparticles with agglomeration. XRD analysis and the scherrers equation estimated the average crystallite size of the nanoparticles to be 0.699nm. Corrosion inhibition study recorded a maximum inhibition efficiency of 62.28% at the highest concentration studied. Irvingia gabonensis leave extract nanoparticles could be an effective alternative for corrosion inhibition in aqueous corrosive media.*

Keywords— Corrosion, Extract, Green synthesis, inhibition, *Irvingia gabonensis,* Nanoparticle,

1. INTRODUCTION (*Heading 1*)

Concerns surrounding the procedures and toxicity associated with conventional nanoparticles synthesis methods necessitated the development of benign, environmentally friendly and sustainable alternatives for nanoparticles production. (Osman *et al,* 2024, Singh *et al,* 2018). In accordance with green chemistry principles, green synthesis approach emphasizes the use of environmentally friendly and sustainable techniques that avoid conventional hazardous chemicals and toxic solvents. (Álvarez-Chimal & Arenas-Alatorre, 2023; Duan *et al.,* 2015; Sharma & Mudhoo, 2010)

The green approach offers numerous benefits including less environmental impact, low production costs and the generation of smaller more benign nanoparticles. By adhering to environmental friendly principles, the green synthesis approach minimizes toxicity by applying green solvents, leveraging natural, biological and agricultural wastes as renewable, cost effective alternatives for synthesis of nanoparticles. (Kulkarni *et al,* 2023, Jafarzadeh *et al,* 2023, Pal *et al,* 2022)

Primarily green synthesis approach focuses on mitigating environmental damage caused by existing pollutants and minimizing health and the environment risks during synthesis. The approach prioritizes the selection of green solvents and reagents, non-toxic reducing and stabilizing agents ensuring ecological compatibility throughout the synthesis pathway. (Krishna *et al,* 2022, Naghdi *et al,* 2015). This is a sharp contrast from the traditional nanoparticle synthesis methods-(sol-gel method, chemical reduction) that rely on harsh chemicals and energy intensive processes with hazardous by-products. Thus integrating and merging green chemistry principles and nanotechnology is considered an emerging contemporary research area crucial in developing more sustainable and cost effective methods for synthesis of stable nanomaterials. (Ilavenil *et al.,* 2025, Adelere & Lateef, 2016; Madani *et al.,* 2022).

Corrosion an electrochemical degradation of metals, is a global challenge that significantly impacts industrial infrastructure, safety, and economic stability, leading to substantial material, energy, and financial loss (Morais *et al.,* 2023, Sesia *et al.,* 2023). This electrochemical degradation process occurs when metals react with their environment, gradually returning to more stable, oxidized states (Schmitzhaus *et al.,* 2024). Conventional corrosion control methods often involve the use of synthetic inhibitors, many of which contain heavy metal ions and toxic organic compounds, posing considerable health and environmental risks. This environmental and health burden has spurred a critical shift towards developing sustainable, eco-friendly, and cost-effective alternatives (Murungi & Sulaimon, 2022, Wang *et al.,* 2023).

Plant extracts mediated nanoparticle have emerged as a promising green corrosion inhibitor. (Wang *et al.,* 2023, Tanwar *et al.,* 2024, Alghamdi, 2023). The synthesis of nanoparticles using plant extracts, known as green synthesis or phytosynthesis leverages the rich array of phytochemicals and other bioactive compounds that are present in the leaves, roots, fruits, and barks of plants (Li *et al.,* 2024, Sharma *et al.,* 2024). These biomolecules act as reducing and capping agents during nanoparticle synthesis, resulting in metallic nanoparticles with inherent function to inhibit corrosion and exhibit desirable properties such as high surface reactivity, tunable size, and often, enhanced stability (Ituen *et al.*, 2020, Tanwar *et al.*, 2024)

The application of plant extracts mediated nanoparticle and plant extracts as corrosion inhibitors is driven by their ability to adsorb onto metal surfaces, forming a protective layer that mitigates corrosion. This protective action involves several mechanisms, primarily surface adsorption, which can be either physio-sorption or chemisorption, leading to the formation of a barrier film. The heteroatoms (e.g., oxygen, nitrogen, sulfur) and electron-rich functional groups within the phytochemicals facilitate strong interactions with metal surfaces, blocking active sites where anodic dissolution and cathodic reactions typically occur (Mamudu *et al.*, 2023, Ani *et al.*, 2020). Plant extracts have been reported to significantly reduce corrosion rates in aggressive acidic environments for materials like mild steel, which is highly susceptible to acidic corrosion. (Kaur *et al.*, 2021, Mamudu *et al.*, 2023, Sowmyashree *et al.*, 2023, Ade, 2022,); and inhibition efficiencies often exceed 90% in various corrosive media (Jebali *et al.*, 2024, El-Hashemy & Almehmadi, 2024). This study investigates the green synthesis of copper nanoparticles using *Irvingia gabonensis* (Ogbono) leaf extract and evaluate its effectiveness as corrosion inhibitors for mild steel in a saltwater.

MATERIALS AND METHODS

Plant Sample Collection

Fresh, mature *Irvingia gabonensis* leaves were identified and harvested from a farm in Amassoma community, Nigeria. The leaves were authenticated in the Department of Agricultural Engineering, Niger Delta University. Harvested leaves were thoroughly washed under running water, air-dried under laboratory conditions until leaves were crispy. The dried leaves were mechanically pulverized into fine powder and stored in sealed containers before extraction.

Figure 1: Fresh *Irvingia gabonensis* Leaves

Seawater Sample Collection

Seawater used in this study was collected from the Brass River in Bayelsa State, Nigeria, and stored in the Chemical Engineering Laboratory of Niger Delta University until needed for the study.

Mild Steel Sample Preparation

The mild steel sample was obtained from Kristorall Global Concept, Yenagoa, Bayelsa State, Nigeria. It was supplied in sheet form with a thickness of 0.5cm. The sheet was manually cut into coupons measuring **4cm×3cm** using a coping saw, with a machine vise employed to maintain precision. To minimize thermal distortion during cutting, cold water was intermittently applied. Each coupon was drilled with a 0.35 cm hole to allow suspension during immersion tests. The surfaces of the coupons were polished using progressively finer grades of sand paper to remove oxide layers and achieve a smooth finish. The polished samples were then rinsed with ethanol, dried at room temperature, and stored in a desiccator until use.

Preparation of plant Extract

50g of powdered *Irvingia gabonensis* leaves were added to a 500mL conical flask containing 250mL of ethanol. The flask was covered with aluminum foil to prevent light exposure and maintained at room temperature for 72 hours, shaking occasionally. The combination was then filtered through Whatman No.1 filter paper, yielding a high-yield extract. The filtrate was left exposed to air for two days to allow complete evaporation of the ethanol, resulting in a concentrated plant extract for use.

Figure 2. *Irvingia gabonensis* leaf extract

Preparation of Synthesized Nanoparticles

Metal salt solution was made by dissolving 14g of copper (II) nitrate in 50mL of deionized water. The solution was heated in a water bath at 60-70°C for 30 minutes. The ethanolic extract of *Irvingia gabonensis* was then progressively added to the copper solution, stirring constantly with a magnetic stirrer. The combination was observed for an apparent color change from leafy green color of the plant extract solution, which indicated the successful production of copper nanoparticles in the solution. To stabilize the nanoparticles, a chitosan solution was prepared. 1g of chitosan was dissolved in 25mL of diluted acetic acid while stirring continuously until completely dissolved. 2 mL of the chitosan solution was added to the copper nanoparticle mixture and gently stirred to ensure even distribution.

Experimental Set-up and Weight Loss Measurement

To achieve the study objectives, five plastic containers were each filled with 250mL of seawater. Five mild steel coupons of dimensions **4cm×3cm** were cleaned, weighed, and immersed in the containers. Weight loss measurement, a widely accepted method for evaluating corrosion rates in metals, was employed. The coupons were fully submerged in the seawater medium, and the weight loss was monitored at intervals of four days over a period of 20 days without the use of an inhibitor. The experiment was then extended for an additional 16 days with the addition of the synthesized extract nanoparticles as an inhibitor, except for the control, which remained without an inhibitor.

At each measurement interval, the coupons were carefully removed, cleaned, initially with ethanol for the early stages and later with water- dried at room temperature for about one hour using a soft cloth, and then weighed to determine the weight loss due to corrosion. The samples were subsequently returned to their respective containers to continue the exposure cycle. The corrosion rate was calculated by comparing the initial weight of each coupon before immersion with the final weight after the designated period. All procedures were conducted at room temperature.

Phytochemical screening of *irvingia gabonensis* leaf extract

Phytochemical screening was performed to identify the presence of bioactive chemicals in *Irvingia gabonensis* leaf extract.

Characterization of Nanoparticles- Nanoparticles were analyzed using:

- **UV–Visible Spectroscopy** - to assess optical characteristics and validate nanoparticle production.
- **X-ray Diffraction (XRD)** -To determine the structural organization of synthesized nanoparticles.
- **Fourier-Transform Infrared Spectroscopy (FTIR)** to determine the functional groups involved in nanoparticle stability.
- **Scanning Electron Microscopy (SEM) coupled with Energy Dispersive X-ray Spectroscopy (EDS)** to investigate the surface morphology, crystalline or amorphous nature of the nanoparticles, and elemental composition. (Banger *et al*, 2025, Khan *et al*, 2022, Pasieczna-Patkowska, *et al*, 2025)

Overall, the procedures for extract preparation, nanoparticle synthesis, and corrosion testing were systematically carried out to ensure reliable and reproducible results.

RESULTS AND DISCUSSION

The results of the synthesis and characterization of copper nanoparticles with *Irvingia gabonensis* leaf extract, including visual observations, UV-Vis spectral analysis, FTIR analysis, SEM imaging, and XRD measurements, are shown below.

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Phytochemical Screening of *Irvingia gabonensis* Extract

A qualitative phytochemical analysis was carried out on the ethanolic extract to identify bioactive compounds responsible for the reduction and capping of nanoparticles. The results are presented below:

Table 1. Results of Phytochemical Screening of *Irvingia gabonensis* Extract

S/No	**Phytoconstituent**	**Result**
1.	Alkaloids	+
2.	Cardiac Glycosides	-
3.	Flavonoids	-
4.	Saponins	+
5.	Tannin	+
6.	Terpenoids	+
7.	Anthraquinone glycosides	+

The presence of alkaloids, saponins, tannins, terpenoids, and anthraquinone glycosides was confirmed by phytochemical analysis of *Irvingia gabonensis's* ethanolic extract. Similar results were found for other plant sections. (Ezeabara *et al.,* 2023). Tannins and saponins are recognized for their antioxidant qualities, which aid in the reduction of metal ions during the synthesis porcess, whereas alkaloids and terpenoids contain functional groups such as hydroxyl and carbonyl, which work as reducing and stabilizing agents, inhibiting nanoparticle aggregate formation. (Otitolaiye *et al.,* 2023, Gebre, 2023).

Visual Observation and UV-Visible Spectroscopy of Nanoparticle

The primary indicator of nanoparticle synthesis is colour of the plant extract solution. (Patil *et al*, 2018, Oyekunle *et al*, 2022). The initial solution of *Irvingia gabonensis* leaf extract exhibited a dark green color. Upon the gradual addition of the extract to the aqueous Copper (II) nitrate solution at 60-70°C, a sequential color transformation was observed from leafy green to dark-brown. This distinct color change is indicative of the interaction of electrons of metallic nanoparticles and incident photons leading to copper ion reduction and nanoparticle formation. (Amjad *et al.,* 2021, Mali *et al*, 2020, Jana *et al*, 2016))

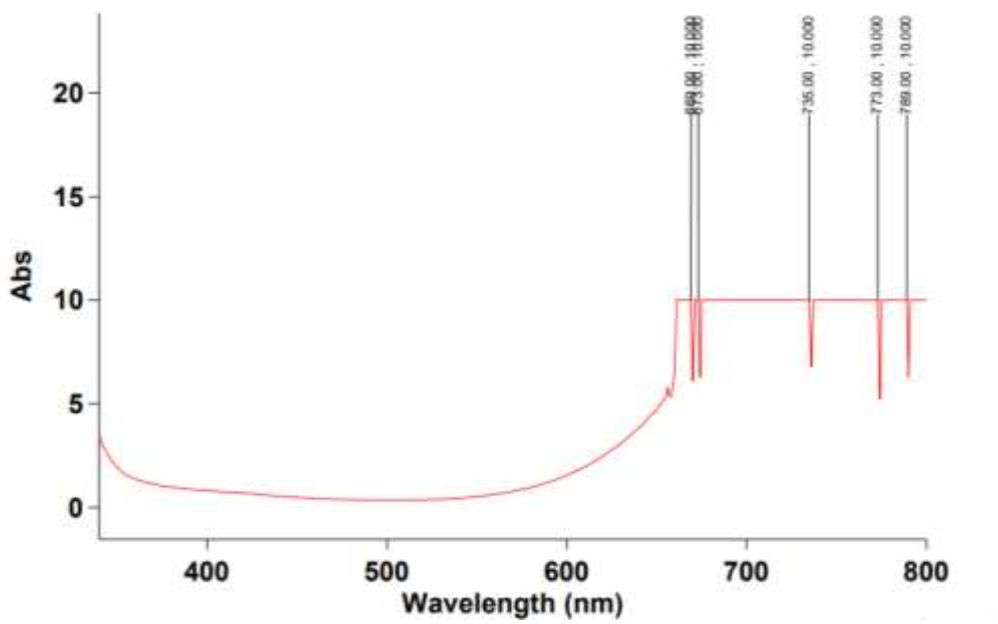

Figure 5: UV-Vis absorption spectrum of $Cu(NO_3)_2$ synthesized by extracts

UV–Visible spectroscopy is an essential tool for analyzing the optical behavior of synthesized nanoparticles. It helps detect electronic transitions in phytochemicals and identifies the possible formation of nanoparticles by revealing specific absorption peaks in the spectrum. The UV–Visible spectral analysis of *I.gabonensis* leaf extract was conducted over a wavelength range of 340–800 nm and is as depicted in Figure 5. UV-Vis revealed a prominent absorption peak at **789 nm** with an absorbance value of **10.abs**. Such a pronounced absorption peak in the near-infrared region suggests the presence of highly conjugated. The observed absorption may be attributed to the π–π transitions of aromatic compounds, such as flavonoids, tannins, and phenolic acids, which are known

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constituents of leaves. These phytochemicals possess strong reducing and stabilizing capabilities, making them suitable agents in the synthesis of metal nanoparticles.

FTIR SPECTROSCOPY

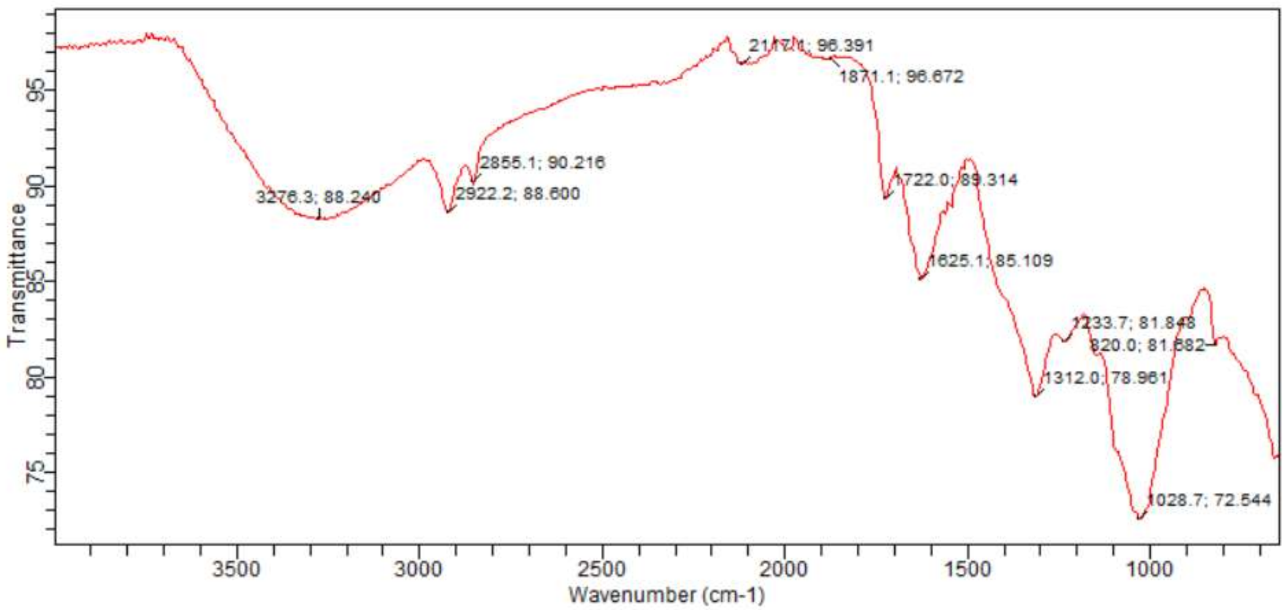

Figure 6: FTIR spectrum of synthesized nanoparticles

Fourier-transform infrared (FTIR) spectroscopy was utilized to determine the biomolecules and functional groups in plant extracts that are responsible for the reduction and stability of produced copper nanoparticles (CuNps). The recorded FTIR spectra, as illustrated in Figure 6, exhibited several distinct absorption bands within the mid-infrared region, specifically at 3276.3 cm^{-1}, 2922.2 cm^{-1}, 2855.1 cm^{-1}, 2172.1 cm^{-1}, 1871.1 cm^{-1}, 1722.0 cm^{-1}, 1625.1 cm^{-1}, 1320.0 cm^{-1}, 1312.0 cm^{-1}, 1233.7 cm^{-1}, and 1028.7 cm^{-1}. The broad peak observed at 3276.3 cm^{-1} corresponds to O–H stretching vibrations, indicative of alcohol and phenol groups, which are commonly found in flavonoids and polyphenols. Peaks at 2922.2 cm^{-1} and 2855.1 cm^{-1} are attributed to single bonds in C–H stretching of alkanes and aldehydes, respectively. The band at 2172.1 cm^{-1} is characteristic of C≡C (alkynes) or C≡N (nitriles), suggesting the presence of triple bond-containing compounds. The sharp absorption at 1722.0 cm^{-1} is due to C=O stretching, consistent with esters and carboxylic acids. The band at 1625.1 cm^{-1} corresponds to aromatic C=C stretching or N–H bonding, further pointing to amines or conjugated systems. Notably, the peaks at 1320.0 and 1312.0 cm^{-1} suggest O–H bending and aromatic C–H deformation, while 1233.7 cm^{-1} indicates C–N stretching of amines or C–O stretching in phenolic compounds. The band at 1028.7 cm^{-1} reflects C–O stretching vibrations, typically associated with alcohols, ethers, and flavonoids. These functional groups strongly suggest the presence of reducing and stabilizing phytochemicals in the extract, supporting its role in the green synthesis process.

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Scanning Electron Microscopy (SEM) Analysis of Synthesized Nanoparticles

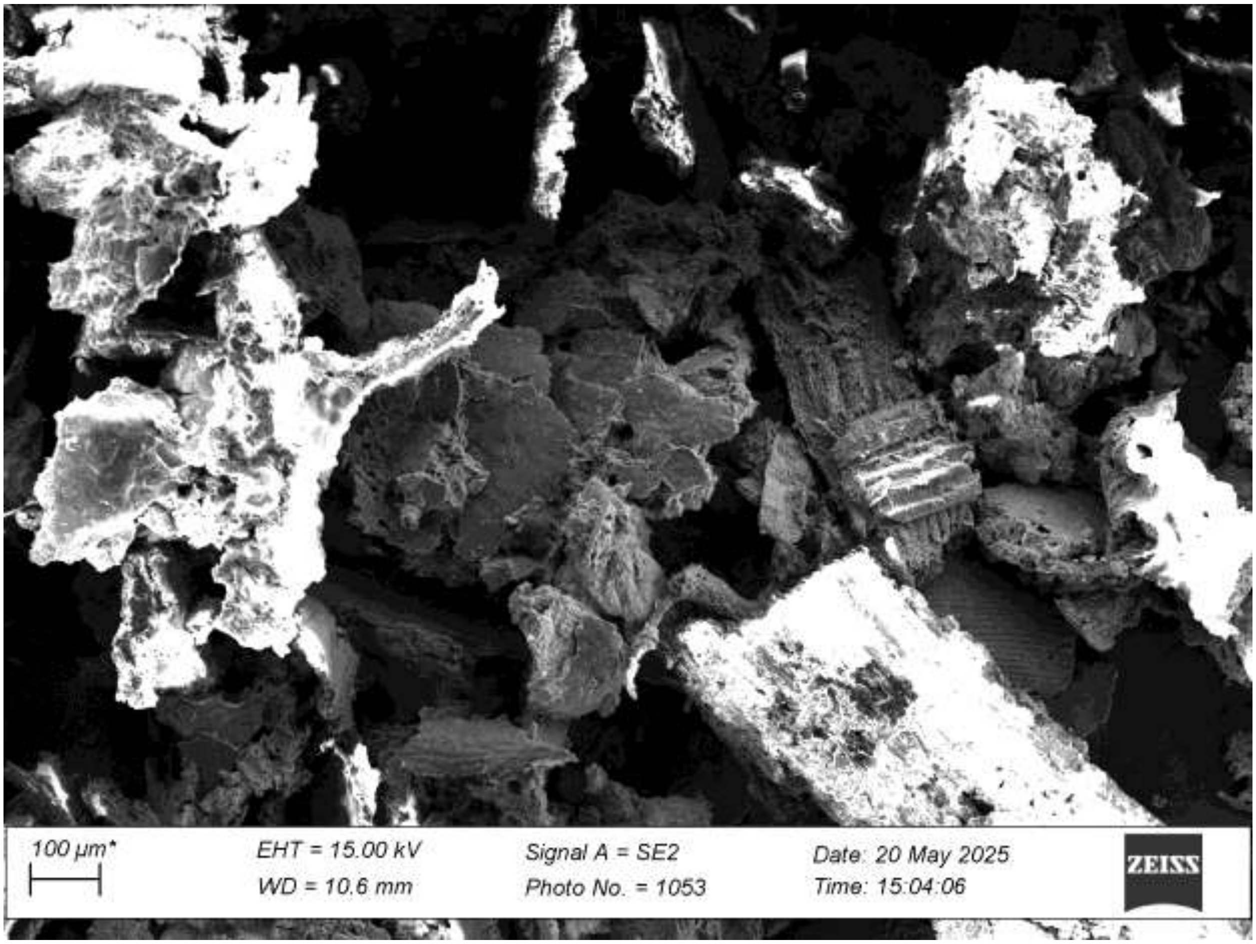
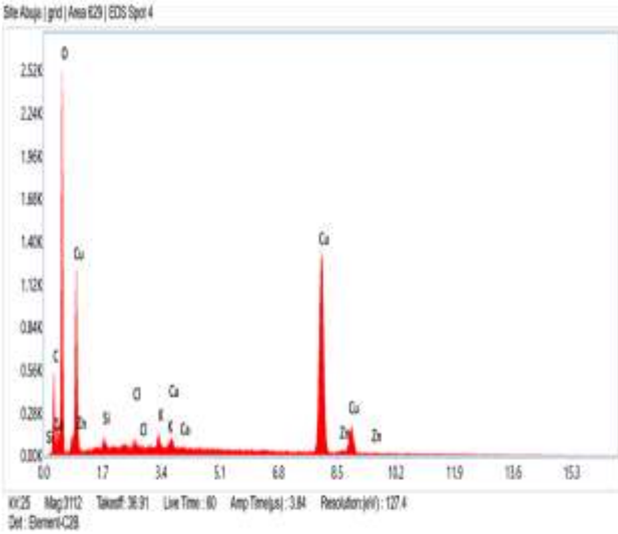


Figure 7: SEM Micrograph Showing the Morphology of CuNps

Visual display of the shape and size of the synthesized nanoparticles is presented in the SEM micrographs above. Figure 7 illustrates the morphological characteristics of copper nanoparticles synthesized via a green route using *Irvingia gabonensis* leaf extract. The image shows a non-homogenous particles in terms of shape and size. The micrograph reveals that the nanoparticles exhibit **irregular shapes with varying sizes** with noticeable **agglomeration.** A common feature in green-synthesized nanomaterials due to the capping action of phytochemicals from plant extracts. The particle agglomeration observed is possibly due to high surface area of the synthesized nanoparticles. The slightly rough surface texture and aggregation of the particles may be attributed to the presence of **bio-organic compounds**—such as flavonoids, tannins, and polyphenols—naturally found in *Irvingia gabonensis*, which function as both reducing and stabilizing agents during synthesis.

This morphological profile is consistent with earlier green synthesis reports where plant extracts facilitated controlled nucleation and growth. For instance, silver nanoparticles synthesized using *Ficus benghalensis* leaf extract also exhibited aggregated spherical particles (Din *et al*, 2025).

Energy Dispersive X-ray (EDX) Analysis



Quant Result - Analysis Uncertainty: 9.27 %

Element	Weight %	MDL	Atomic %
C K	30.25	0.85	45.38
O K	41.04	0.25	46.21
Si K	0.34	0.08	0.22
Cl K	0.20	0.09	0.10
K K	0.35	0.12	0.16
Ca K	0.36	0.12	0.16
Cu K	26.95	0.27	7.64
Zn K	0.51	0.29	0.14

Figure 8 (A & B): *EDX spectra and elemental composition of copper nanoparticles synthesized using Irvingia gabonensis extract.*

EDX was used to determine the elemental composition of the produced copper nanoparticles. The analysis revealed a detailed elemental breakdown, confirming the successful incorporation of copper and other elements originating from the plant extract used in the green synthesis process. Figure 8a shows the EDX spectrum obtained for synthesized nanoparticles. Peaks corresponding to elemental copper, oxygen and carbon were clearly defined, with no additional peaks present, this demonstrates the purity of the extract synthesized nanoparticles. It is understood in theory that the presence of carbon and oxygen is likely from the capped bioactive compounds. Copper atoms on the surface are oxidized to yield minute quantities of CuO and Cu_2O. The bioreduction of Cu to CuNps is facilitated by the extracts molecules containing hydroxyl groups. (Murthy *et al*, 2020).
The EDX spectrum showed that oxygen and carbon were the most abundant elements present in the sample, indicating the strong presence of bio-organic compounds. These elements are commonly found in plant-mediated nanoparticle synthesis and are attributed to natural phytochemicals such as flavonoids, tannins, saponins, and polyphenols, which function as both reducing and stabilizing agents.

Most significantly, copper (Cu**)** was detected at a high concentration, validating the effective reduction of copper ions to form metallic copper nanoparticles. The presence of copper at this magnitude confirms the core composition of the nanoparticles synthesized. Overall, the EDX analysis supports the presence of elemental copper and confirms the successful synthesis of copper nanoparticles via a green route using extract of *Irvingia gabonensis.* The high oxygen and carbon content further affirms the bio molecular capping of the nanoparticles, which contributes to their stability and prevents agglomeration.

X-Ray Diffraction Analysis (XRD)

X-ray diffraction analysis was done on the synthesized nanoparticles to understand the crystalline nature of the nanoparticles. The diffractogram showed distinct and sharp peaks and the presence of well-defined crystalline phases commonly found in mineral-rich biosynthesized materials.

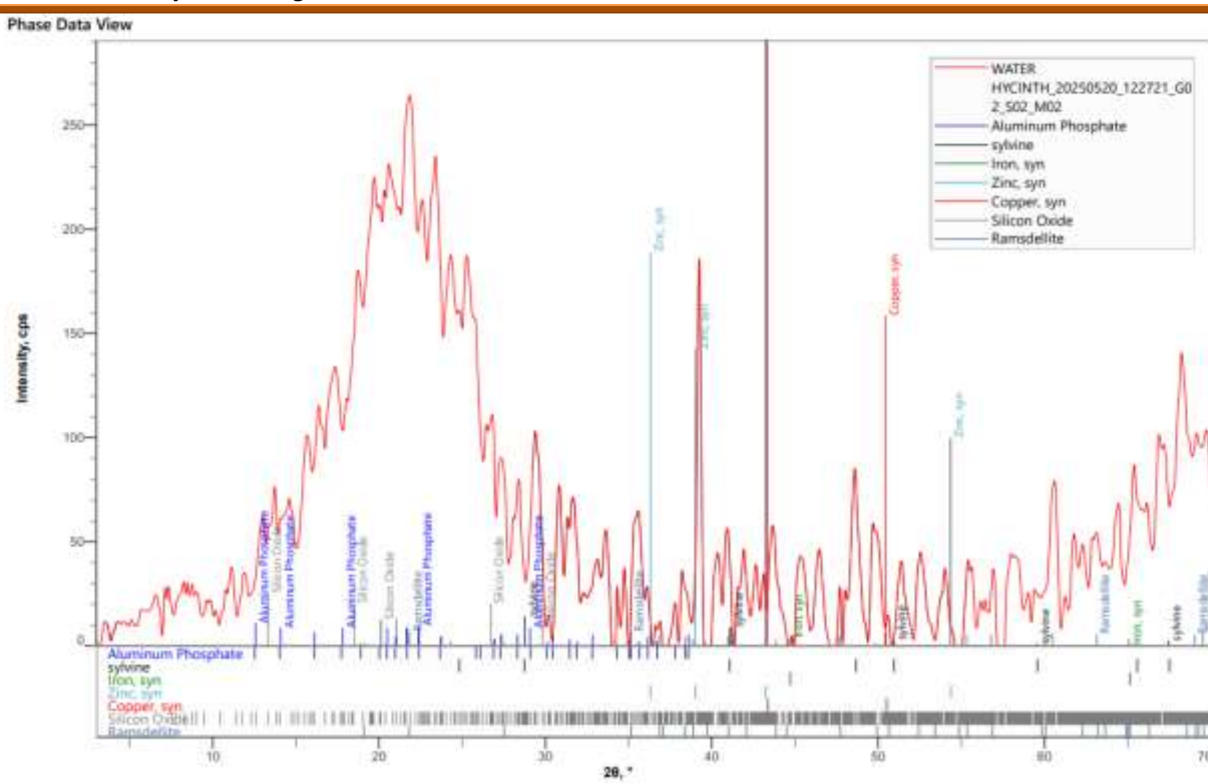


Figure 9: XRD profile with prominent peak at 2θ = 22.67°

The Debye–Scherrer equation was used to estimate the average crystallite size. The crystallite size of the particles was approximately **6.99Å (0.699nm).** This indicates that the particles formed were ultra-small particles. The ultra-small size of the nanoparticle synthesized could be as a result of the capping and stabilization mechanism of plant extract phytochemicals during synthesis which provides a covering of the particles surfaces preventing further attachment of materials to the surface.

Corrosion Studies - Corrosion rate (CR) was estimated with the following formula (ASTM, 2012, Malaret, 2022).

$$CR = \frac{(87.6 \times W)}{(D \times A \times T)} \times 10^{-4}\,(cm/hr)$$

Where:
CR = Corrosion rate (cm/hr)
W = Weight loss (g), calculated as W = M_initial - M_final
D = Density of mild steel (7.85 g/cm³)
A = Surface area of the exposed sample (cm²)
T = Exposure time (hours)
87.6×10^{-4} = Unit conversion factor to express corrosion rate in cm/hr
The inhibition efficiency (IE%) of the green inhibitor is calculated using the equation (Kreysa & Schutze, 2007):

$$IE\% = \left(\frac{Wo - Wi}{Wo}\right) \times 100$$

Where:
Wo = Weight loss without an inhibitor
Wi = Weight loss with the inhibitor

Table 2: Corrosion rate data and percentage efficiency of nanoparticles

Inhibitor Conc (ml)	CR Before Inhibition	CR After Inhibition	Efficiency (%)

2	1.75	1.04	40.5
4	1.27	0.68	46.45
6	1.57	0.70	55.41
9	1.75	0.70	60.0
11	1.75	0.66	62.28
0	1.40	1.40	0.00 control

Table 2 Presents corrosion data and percentage efficiency of nanoparticles in corrosion control. The ability of the nanoparticles to prevent mild steel corrosion in seawater was examined. The weight loss method was used to investigate the effect of concentration on synthesized nanoparticles' ability to suppress metal corrosion in seawater. Results showed an increase in inhibitor efficiency with increase in concentration. Maximum inhibition efficiency of 62.28% at a concentration of 11ml of extract nanoparticles studied. The inhibition is likely due to adsorption of plant extract nanoparticles on the metal surface.

The corrosion rates before and after inhibition and inhibition efficiency on a mild steel coupons in seawater are shown in table 2. From obtained gravimetric data, addition of nanoparticles inhibitor caused a decrease in corrosion rates and increase in inhibitor efficiency. A gradual increase in inhibitor concentration lead to an increase in inhibitor efficiency. Similar results were obtained by Al-Mhyawi *et al*, 2023 using tobacco leaves extract. The mechanism of action is via absorption onto the metallic surface and blocking anodic and cathodic sites.

Nanoparticles improves the protective barrier formed on metal surfaces and corrosion resistance by increasing surface coverage and adherence on the metal surface. Corrosion inhibition at the nanoscale allows the nanoparticles to successfully permeate surface defects. (Pourhashem *et al,* 2020, Verma *et al,* 2024)

Conclusion

Irvingia gabonensis leaves extract successfully mediated the synthesis of copper nanoparticles using Copper (II) Nitrate salts as the precursor. Phytochemical analysis of the leaf extract confirmed the presence of alkaloids, tannins, Saponins, terpenoids and Anthraquinone glycosides. Synthesis of nanoparticles was confirmed by color change from green to brown. UV-visible spectroscopy revealed a prominent absorption peak at 789nm. XRD together with the Scherer’s equation estimated the average crystalline size of the nanoparticles to be 0.699nm. SEM micrographs showed non-homogeneous, irregularly shaped particles with agglomeration. EDX analysis confirmed the elemental composition with successful incorporation of copper and other compounds in the synthesis process. Corrosion inhibition studies revealed an increase in inhibitor efficiency with increase in nanoparticle inhibitor concentration. Maximum inhibition efficiency of 62.28% was observed at the highest concentration studied.

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