GREEN SYNTHESIS OF NANOMATERIALS FOR CO_2 CAPTURE

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Introduction:

Atmospheric CO_2 levels have risen sharply, now exceeding 420 parts per million (ppm), compared to around 280 ppm in pre-industrial times. This rise in CO_2 has contributed to a noticeable increase in global temperatures, average surface temperatures have risen by over 1°C, leading to more frequent heatwaves, melting glaciers, and rising sea levels. These changes emphasize the urgent need for effective and sustainable carbon capture technologies.

Nanomaterials are highly promising for this purpose due to their large surface area, porosity, and strong CO_2 adsorption capacity. Zinc oxide (ZnO) nanoparticles, in particular, are valued for their thermal stability, chemical resistance, and ability to interact efficiently with CO_2 molecules.

This project focuses on the green synthesis of ZnO nanoparticles using natural extracts from banana peel, aloe vera, and eucalyptus. These extracts contain bioactive compounds that reduce metal ions, allowing nanoparticles to form without hazardous chemicals. Using agricultural waste like banana peels and common plant materials like aloe vera, and eucalyptus makes the process eco-friendly and cost-effective. By promoting green nanotechnology, this research supports sustainable development and reduces the environmental impact of nanoparticle production. It contributes to global efforts to combat climate change through innovative, low-impact carbon capture methods.

Objectives:

1. To synthesize the nanoparticles from Zn metal granular.
2. To extract bioactive compounds from banana peel, aloe vera, and eucalyptus.
3. Characterization of plant extract.
4. Preparation of Metal organic frameworks.
5. Characterization of Metal organic frameworks.
6. Adsorption studies of Metal organic frameworks.
7. Comparative studies of CO_2 adsorption capacity.
8. To apply AI techniques for optimizing CO_2 adsorption in green metal-organic frameworks.

Methodology:

Materials and Equipment: Banana peel, Eucalyptus leaves, Aloe vera gel, Zinc metal granular, Nitric acid, Distilled water, Sodium hydroxide, Ethanol, Citric acid, Petri dish, Oven, Filter paper, Magnetic stirrer, and Glassware.

Fresh banana peels (Dried and powdered, 25 g), aloe vera gel (40 g), and eucalyptus leaves (Dried and powdered, 16 g) were mixed with distilled water each. The mixtures were stirred using a magnetic stirrer. The solutions were then filtered to obtain the respective plant extracts and further characterized using Fourier Transform Infrared Spectroscopy.

Preparation of Zinc precursor & Organic ligand: 20ml of Nitric acid along with 80ml of distilled water was mixed with 5.5g of Zinc metal granular to form Zinc nitrate hexa hydrate which is used as precursor. Weigh 9.61g of Citric acid crystals and dissolve using Distilled water to make it up to 100ml and to be used as organic ligand.

Preparation of plant-based MOFs: 10 ml of plant extract and 34 ml of citric acid were added to the prepared zinc nitrate precursor. The pH was adjusted, and the mixture was centrifuged, vacuum filtered, dried, and stored. The obtained Metal Organic Framework were further characterized using X-Ray Diffraction.

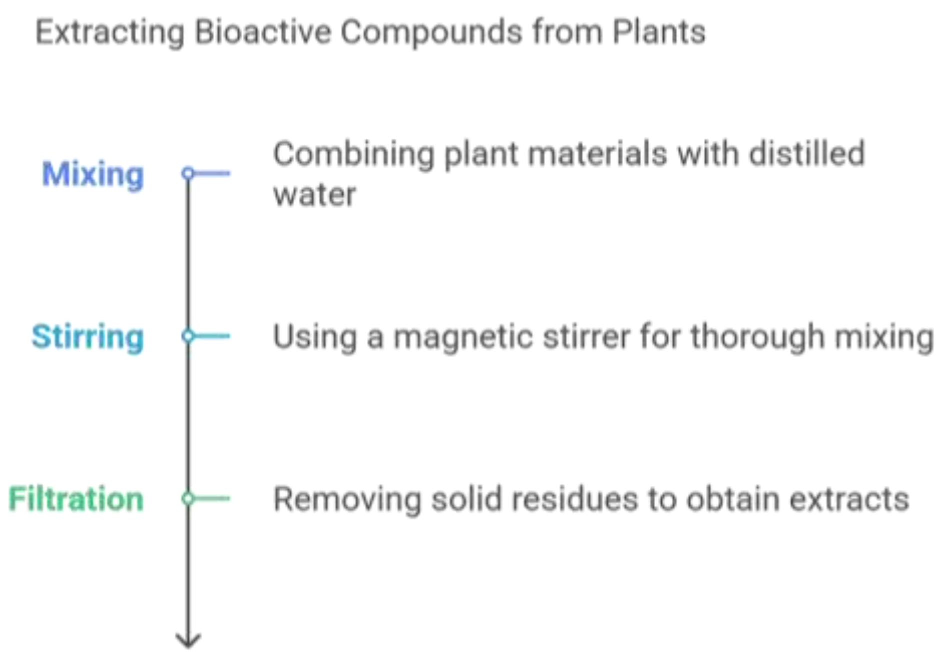

Fig 1: Extracting Bioactive Compounds from Plants

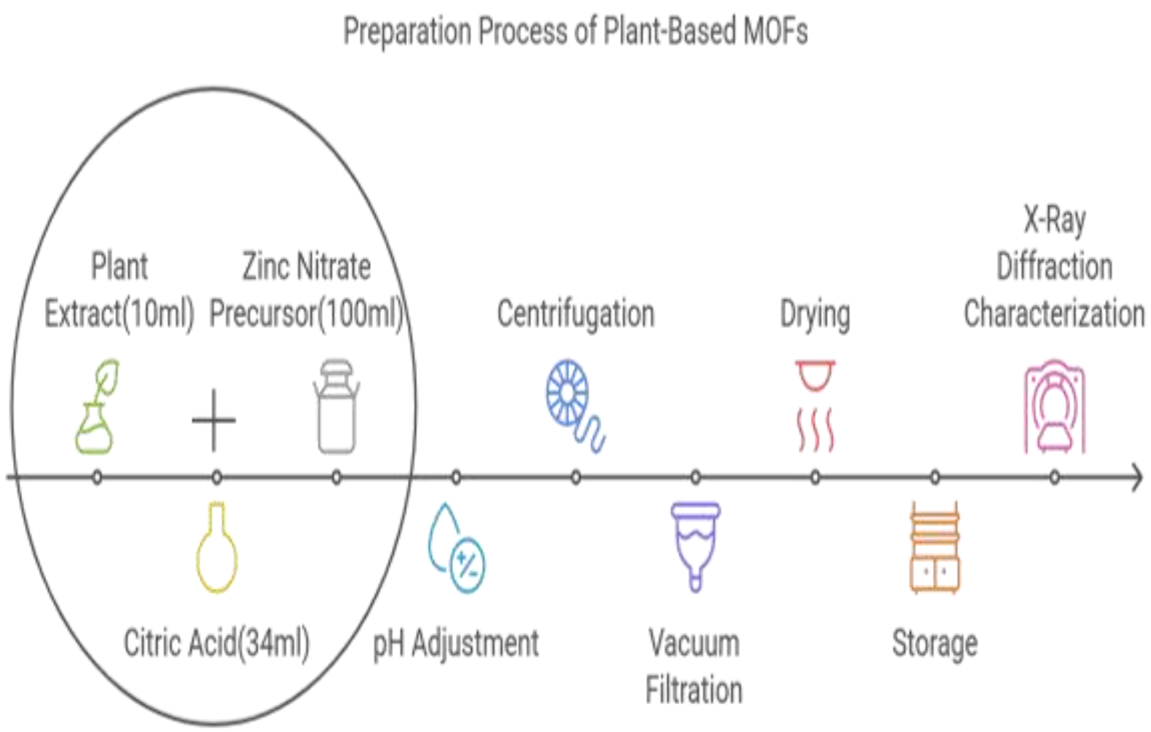

Fig 2: Preparation Process of Plant-Based MOFs

Adsorption studies of Metal Organic Frameworks: Column studies will be conducted to evaluate the CO_2 adsorption capacity of the synthesized nanomaterials under dynamic conditions. A small-scale continuous CO_2 adsorption setup is made using a CO_2 gas cylinder. The Prepared MOF is packed in a vertical column, and CO_2 is passed through it. The amount of CO_2 adsorbed is measured over time to study the material's performance. Comparative analysis will be done across different plant-based nanomaterials. Additionally, AI techniques will be employed to analyze patterns, optimize parameters, and predict performance trends for enhanced carbon capture efficiency, suitable for small scale experimental datasets.

Results and Conclusion:

Characterization of Plant extracts by FTIR:

a. Banana Peel

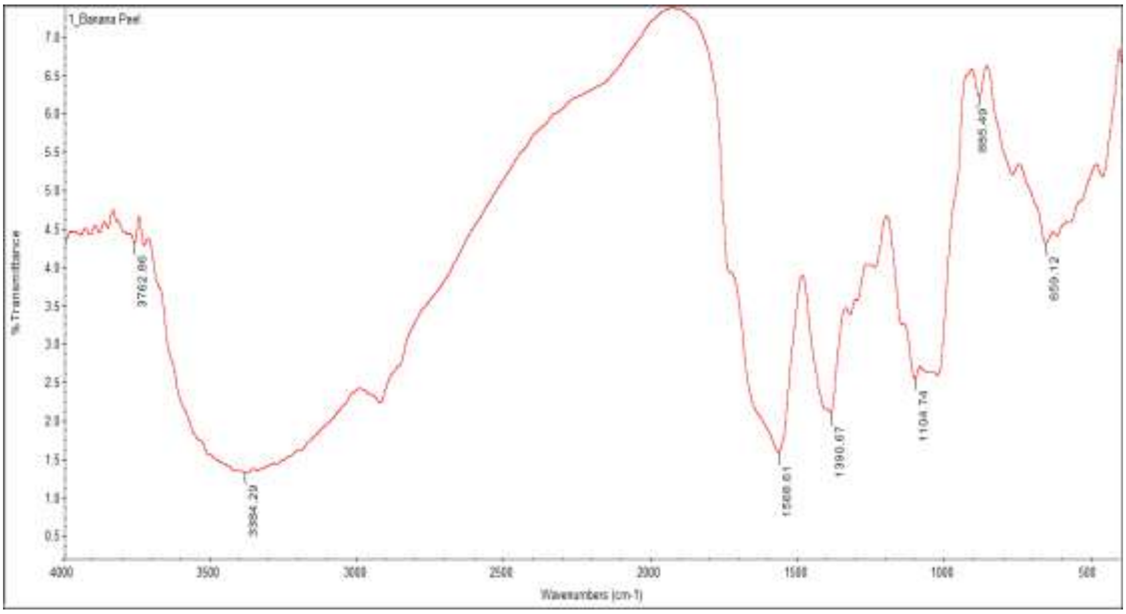

Fig 3: FTIR results of Banana peel

This FTIR spectrum of the sample (presumably Aloe Vera) displays characteristic peaks for O-H stretching (3389 cm^{-1}), C=O or C=C stretching (1605 cm^{-1}), C-H bending (1421 cm^{-1}), and C-O stretching and polysaccharide vibrations (1254–1061 cm^{-1}), indicating the presence of alcohols, phenols, carbonyls, and carbohydrates.

b. Eucalyptus leaves

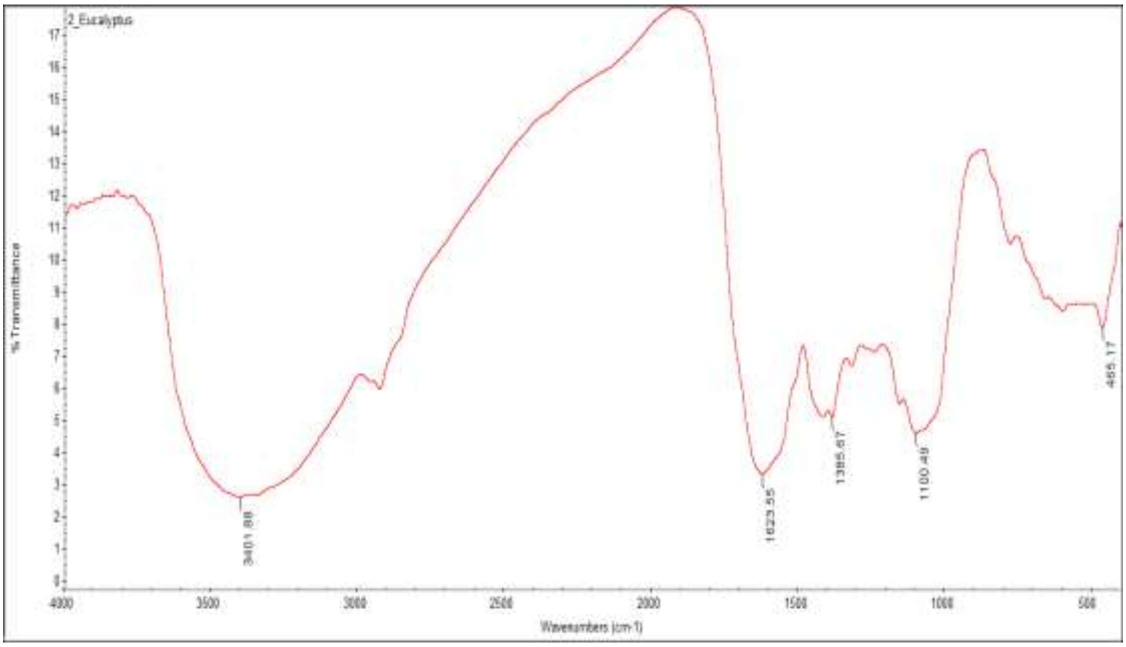

Fig 4: FTIR Results of Eucalyptus leaves

This FTIR spectrum of eucalyptus shows characteristic absorption peaks indicating the presence of O-H (3401 cm^{-1}), C=C (1623 cm^{-1}), C-H bending (1385 cm^{-1}), C-O (1100 cm^{-1}), and fingerprint region vibrations (below 600 cm^{-1}).

c. Aloe vera

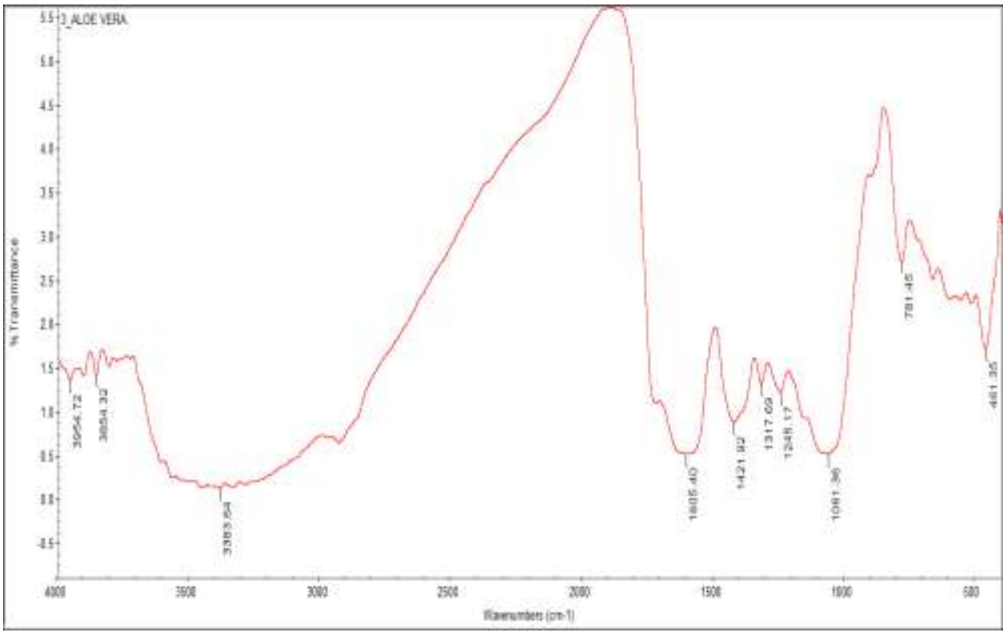

Fig 5: FTIR Results of Aloe vera

This FTIR spectrum of Aloe Vera shows broad O-H stretching (~3389 cm^{-1}), C=O or C=C stretching (~1605 cm^{-1}), C-H bending (~1421 cm^{-1}), and strong C-O and polysaccharide-related peaks (1254–1061 cm^{-1}), indicating the presence of hydroxyl, carbonyl, and carbohydrate functional groups.

Characterization of Plant-based MOF by XRD:

a. Banana- Based ZnO MOF

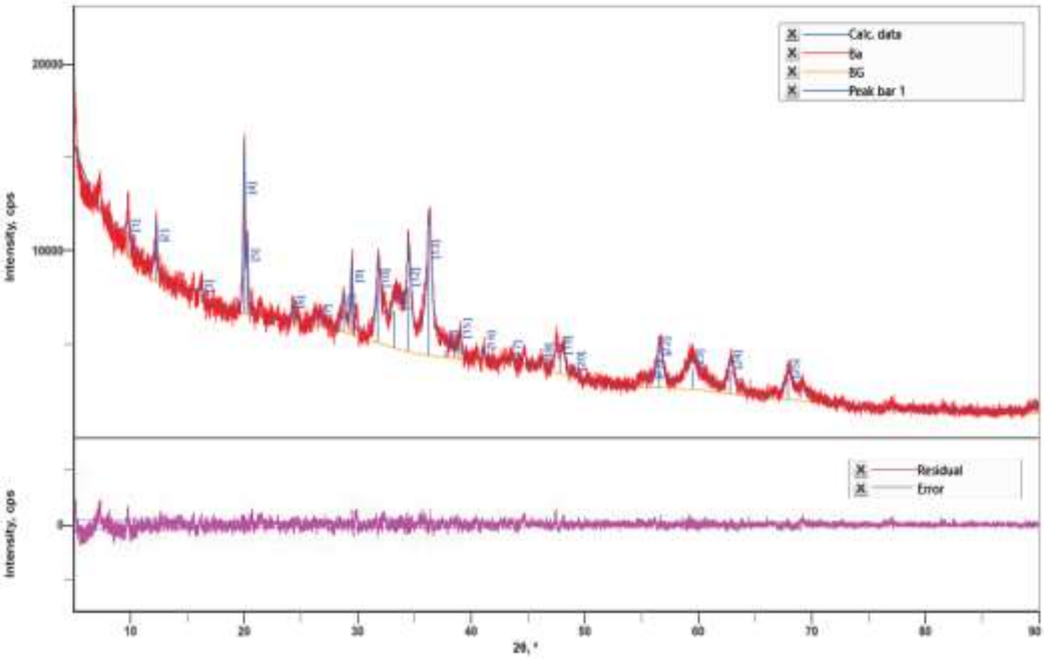

Fig 6: XRD Results of Banana- Based ZnO MOF

b. Eucalyptus leaves- Based ZnO MOF

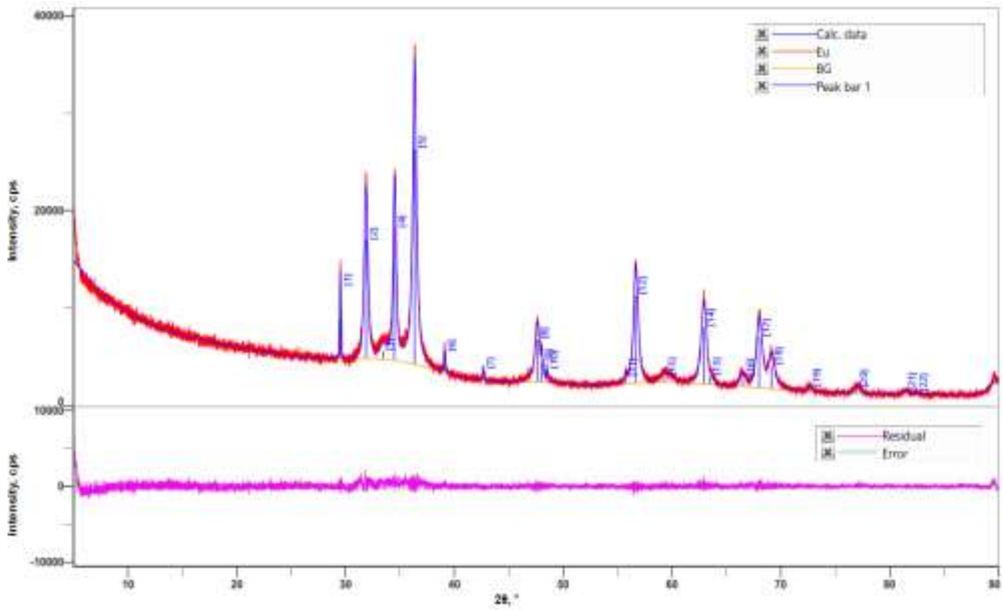

Fig 7: XRD Results of Eucalyptus leaves- Based ZnO MOF

c. Aloe vera- Based ZnO MOF

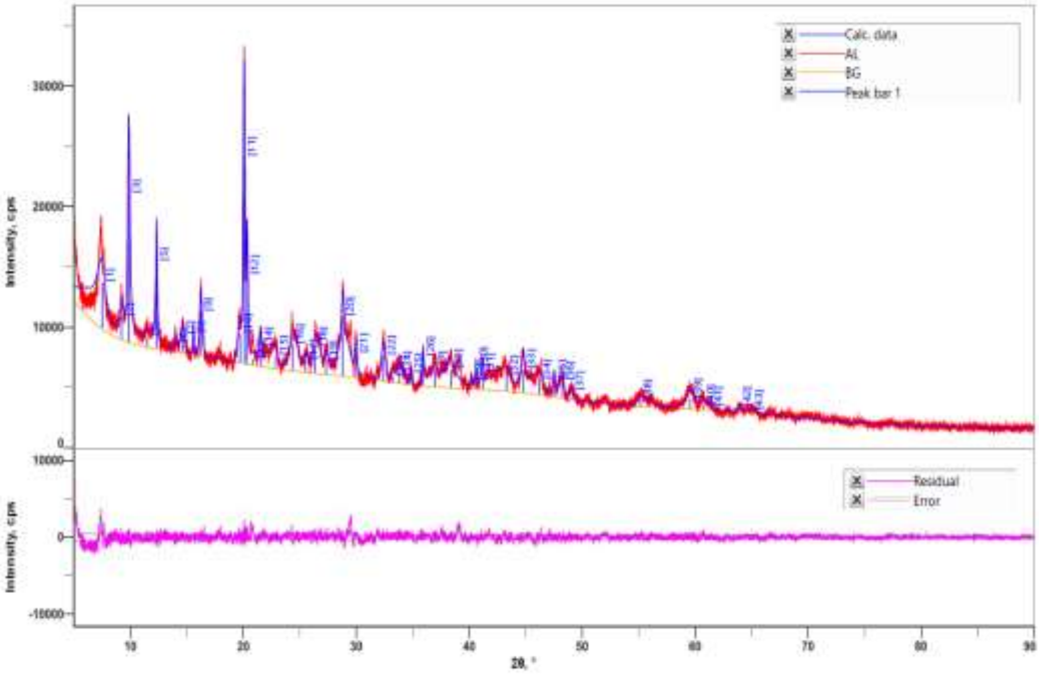

Fig 8: XRD Results of Aloe vera- Based ZnO MOF

The XRD analysis of the plant-based ZnO MOFs shows successful crystalline structure formation in all three samples. The Eucalyptus-based ZnO MOF displays the highest crystallinity with sharp and intense peaks, indicating well-defined crystal planes. Aloe vera-based ZnO MOF also shows distinct peaks but with slightly lower intensity, suggesting moderate crystallinity. The Banana-based ZnO MOF exhibits broader and less intense peaks, indicating relatively lower crystallinity and possibly smaller crystallite size. These differences reflect the varying influence of plant extract composition on the MOF formation.

Project Outcomes & Industry Relevance:

This project focuses on the green synthesis of ZnO-based nanoparticles using plant extracts for carbon dioxide capture. The approach is environmentally friendly, cost-effective, and utilizes renewable natural resources. XRD analysis confirmed the crystalline nature of the synthesized MOFs, indicating good stability and potential adsorption capability. These materials can effectively adsorb CO_2 due to their high surface area and porosity.

The project contributes to sustainable nanotechnology and climate change mitigation efforts. It offers an alternative to traditional synthesis methods that rely on toxic chemicals. In real-world applications, such materials can be used in industrial CO_2 capture systems in sectors like power generation and cement manufacturing.

Additionally, they can be incorporated into filters, membranes, or packed columns in dynamic conditions. This work demonstrates how green chemistry can drive innovation in carbon capture technologies.

Working model vs. Simulation/Study:

Column studies will be conducted to evaluate the dynamic adsorption performance of the synthesized ZnO-based MOFs under continuous flow conditions.

Project Outcomes and Learnings:

The project successfully achieved the green synthesis of ZnO-based nanoparticles using plant extracts like banana peel, aloe vera, and eucalyptus. These materials have shown potential for carbon dioxide capture due to their eco-friendly and sustainable origin.

Through the process, we learned how to design and implement a chemical synthesis route using natural materials, optimize experimental conditions, and compare the effectiveness of different extracts. We gained practical experience in planning, executing, and analyzing a research project, while also improving our problem-solving, teamwork, and scientific reporting skills.

Future Scope:

1. Scale-Up for Industrial Applications: Developing scalable, cost-effective green synthesis methods for nanomaterials can support deployment in large-scale carbon capture systems.
2. Integration with Renewable Energy: Coupling green-synthesized nanomaterials with renewable-powered CO_2 capture units (e.g., in solar farms or bioenergy plants) can improve sustainability.
3. Enhanced Selectivity and Efficiency: Future research can focus on tuning the surface chemistry of nanomaterials to improve CO_2 selectivity over other gases like N_2 or CH_4.

4. Reusability and Regeneration: Developing nanomaterials that retain their CO_2 capture efficiency over multiple adsorption-desorption cycles would make processes more economically viable.
5. Hybrid Nanomaterials: Combining green-synthesized nanomaterials with polymers, MOFs, or bio-based matrices can create hybrid materials with superior CO_2 capture performance.
6. Application in Direct Air Capture (DAC): With high surface area and functionalization, green nanomaterials can be adapted for low-concentration CO_2 capture from ambient air.
7. Carbon Sequestration and Utilization: Captured CO_2 can be converted into value-added products (e.g., fuels, chemicals), aligning with circular economy goals.
8. Eco-Friendly Life Cycle: Since the materials are green-synthesized, they may offer better biodegradability and lower environmental toxicity compared to traditional materials.
9. Custom Design via Green Routes: Green chemistry approaches (using plant extracts, microbes, etc.) offer flexibility in designing nanomaterials with specific shapes and active sites.
10. Policy and Commercial Interest: With increasing carbon taxation and climate goals, green nanomaterials for CO_2 capture may gain attention from industries and governments for sustainable decarbonization.