Research Proposal

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Title: **Green Synthesis of Phyllanthus emblica Seed Extract Mediated ZnO–NiO/Coconut Shell Derived Bio-Carbon Nanocomposites for High-Performance Supercapacitors**

Abstract

The growing demand for sustainable energy storage has driven the search for eco-friendly, high-performance supercapacitors due to their superior power density, fast charge–discharge capability, and long cycle life. This research proposes a green synthesis route for zinc oxide (ZnO) and nickel oxide (NiO) nanocomposites using Phyllanthus emblica (Amla) seed extract as a natural reducing and stabilizing agent. The bio-mediated ZnO–NiO nanoparticles will be anchored onto coconut shell–derived activated carbon, forming a hybrid ZnO–NiO/bio-carbon nanocomposite for supercapacitor electrodes. Comprehensive characterization (FTIR, UV, XRD, SEM/TEM, XPS, BET) will elucidate structure–property relationships, while electrochemical testing (CV, GCD, EIS) will correlate nanoscale features with charge storage and transport. The study aims to optimize synthesis parameters, structural morphology, and electrochemical performance for achieving high specific capacitance (>850 F/g), energy density (>35Wh/kg), and long-term cycling stability (>2000 cycles). This green nanocomposite-based electrode system promises a cost-effective, scalable, and environmentally sustainable pathway for next-generation energy storage devices.

Keywords: Phyllanthus emblica (Amla); coconut shell; biomass; ZnO—NiO nanoparticles, supercapacitors.

1. Introduction

Supercapacitors, bridging the gap between conventional capacitors and batteries, have emerged as vital components for renewable energy systems and portable electronics. However, developing electrode materials that simultaneously offer high energy and power densities remains a challenge. Metal oxides such as ZnO and NiO possess remarkable pseudocapacitive behavior and stability, while bio-derived carbon provides a conductive and porous network facilitating charge transport. Phyllanthus emblica (Amla) seed extract contains rich phytochemicals (polyphenols, flavonoids, and ascorbic acid) promotes uniform nanoparticle nucleation and stabilization and its natural antioxidants like tannins and gallic acid serves as a bio reducing agent for nanoparticle synthesis, eliminating toxic chemicals. Coconut shell, a lignocellulosic biomass abundant in India, is an ideal precursor for high-surface-area activated carbon through carbonization and KOH activation. It ensures high surface area, excellent conductivity, and hierarchical porosity. When integrated with ZnO–NiO nanostructures via green synthesis, it forms a synergistic hybrid exhibiting enhanced electrochemical performance. This research addresses the need for a sustainable, low-cost, and high-performance electrode material through a bio-inspired synthesis route.

2. Literature Review

Recent advancements in green nanotechnology have focused on integrating biogenic metal oxide nanocomposites with biomass-derived carbon materials to develop sustainable, high-performance supercapacitor electrodes.

Lee et al. (2021) demonstrated the successful synthesis of high-surface-area activated carbon (1567 $m^2\ g^{-1}$) from coconut shells via hydrothermal carbonization and KOH activation. Their optimized material achieved a remarkable specific capacitance of 449 $F\ g^{-1}$ in a three-electrode system and an energy density of 48.9 $Wh\ kg^{-1}$ in a solid-state supercapacitor device, highlighting the immense potential of this biomass source when combined with an appropriate synthesis route.

Prakash & Balaji (2023) successfully demonstrated the use of Phyllanthus emblica fruit extract for the synthesis of stable zinc oxide nanoparticles, highlighting the potential of this plant's rich phenolic content for nanomaterial fabrication.

Yoon and Choi (2024) revealed that hybrid ZnO–NiO/C composites derived from biomass carbon deliver high energy density and rate capability due to synergistic effects between metal oxides and carbon matrices.

Phytochemical-rich extracts such as those from Phyllanthus emblica, containing polyphenols, flavonoids, and vitamin C, facilitate uniform nanoparticle formation and prevent agglomeration, enhancing surface redox activity (Sharma et al., 2023).

ZnO–NiO nanocomposites show superior redox activity and synergistic charge storage (L. Wang et al., Nano Energy, 2021).

However, studies combining Amla seed extract-mediated ZnO–NiO with bio-carbon derived from coconut shell are scarce. This project fills that gap by integrating natural extract synthesis and biomass carbonization for scalable energy storage material development.

3. Research Objectives

1. To synthesize ZnO–NiO/bio-carbon nanocomposites using Phyllanthus emblica seed extract as a natural reducing and stabilizing agent.
2. To prepare and activate coconut shell-derived bio-carbon with optimized porosity and conductivity.
3. To characterize the synthesized materials using FTIR, UV, XRD, SEM, TEM, BET, and Raman spectroscopy.

4. To evaluate the electrochemical performance using cyclic voltammetry (CV), galvanostatic charge–discharge (GCD), and electrochemical impedance spectroscopy (EIS).
5. To fabricate and electrochemically evaluate symmetric supercapacitor devices, comparing their performance against chemically synthesized analogs.
6. To compare performance with other plant-extract-mediated materials and assess scalability for industrial application.

4. Methodology

Synthesis of Coconut Shell Activated Carbon (CSC)

* Raw material: Coconut shell biomass (cleaned, dried, crushed).

*Carbonization: Performed at 500–700°C under N_2 atmosphere to produce bio-char.

*Activation: KOH or H_3PO_4 treatment followed by re-carbonization at 800°C to enhance porosity and surface area.

*Purification: The resulting activated carbon will be thoroughly washed with HCl and distilled water to a neutral pH and dried.

* This activated carbon will serve as a high-conductivity support for the nanocomposites.

Green Synthesis of ZnO–NiO Nanoparticles

*****Phyllanthus emblica seeds are shade-dried, powdered, and extracted using distilled water (60°C, 2 h) to obtain the bio-reductant extract. The extract will be filtered and used as a reducing and capping agent.

*Zinc nitrate hexahydrate [$Zn(NO_3)_2 \cdot 6H_2O$] and nickel nitrate hexahydrate [$Ni(NO_3)_2 \cdot 6H_2O$] will be mixed with the Amla seed extract.

* The solution will be adjusted to pH 10 using NaOH and heated for precipitation.

* The precipitate will be filtered, washed, and calcined at 400 °C for 2 hours to obtain ZnO–NiO nanocomposites.

Composite Fabrication

*ZnO–NiO nanoparticles are ultrasonically mixed with bio-carbon (1:1 or optimized ratio) to form the **ZnO–NiO/C composite**.

*The composite is coated on nickel foam electrodes using PVDF binder and NMP solvent. (Active material (80%), carbon black (10%), and PVDF binder (10%) will be dispersed in N-Methyl-2-pyrrolidone (NMP) to form a slurry).

*The ZnO–NiO nanoparticles and bio-carbon will be mixed (70:30 ratio) via ultrasonication and thermally annealed at 200 °C.

*The slurry will be coated onto nickel foam current collectors and dried to fabricate the working electrodes.

Characterization Techniques

Structural: XRD, FTIR, UV vis and Raman spectroscopy.

Morphological: SEM, TEM, and EDX analysis.

Surface: BET surface area and pore size distribution.

Electrochemical: CV, GCD, EIS using three-electrode setup in 1M KOH electrolyte.

5. Timeline (3 Years)

Year 1	Literature review, collection of Phyllanthus emblica seeds & coconut shell, synthesis of bio-carbon and ZnO–NiO nanoparticles, preliminary characterization
Year 2	Optimization of synthesis parameters, composite fabrication, electrochemical studies, publication of initial results
Year 3	Advanced analysis (EIS, long-cycle testing), comparative studies, thesis writing, and publication of high-impact journal papers

6. Resources

Laboratory access for synthesis (furnace, centrifuge, sonicator).

Characterization facilities (XRD, SEM, TEM, FTIR, BET).

Electrochemical workstation for CV, GCD, EDX and EIS.

Chemicals: $Zn(NO_3)_2 \cdot 6H_2O$, $Ni(NO_3)_2 \cdot 6H_2O$, KOH, NMP, PVDF.

Local sourcing of Amla seeds and coconut shell biomass.

7. Ethical Considerations

All materials used are environmentally benign and non-toxic. Waste management and solvent disposal will follow institutional environmental safety protocols.

8. Expected Outcomes and Significance

*Successful green synthesis of ZnO–NiO/C nanocomposites using Amla seed extract.

*Development of sustainable, scalable electrode materials with high electrochemical performance (>850 F/g).

*Achievement of energy density >35 Wh/kg and cycling stability >2,000 cycles.

*Potential for industrial adaptation of biomass and green nanomaterials in next-generation supercapacitors.

*Contribution to the field of green sustainable nanotechnology.

9. References

1. Yoon, J., & Choi, H. (2024). Hybrid ZnO–NiO/C composites derived from biomass carbon for enhanced supercapacitor performance. **Journal of Energy Chemistry, 92**, 311–324. https://doi.org/10.1016/j.jechem.2024.03.021

2. Li, H., Zhang, Y., & Wang, X. (2023). Green synthesis of ZnO–NiO nanocomposites using plant extracts for high-performance supercapacitors. **Green Chemistry**. https://doi.org/10.1039/D3GC01245B

3. Suresh, R., Karthikeyan, B., & Senthilkumar, M. (2024). Synergistic effect of ZnO–NiO nanocomposites in bio-carbon supported electrodes for supercapacitors. **Electrochimica Acta, 489**, 142037. https://doi.org/10.1016/j.electacta.2024.142037

4. Singh, A., Verma, R., & Yadav, D. (2024). Plant-mediated synthesis of ZnO nanoparticles and their electrochemical behavior. **Journal of Alloys and Compounds, 960**, 171256. https://doi.org/10.1016/j.jallcom.2024.171256

5. Zhang, Q., Huang, X., & Chen, Y. (2024). Coconut shell derived activated carbon for high-energy supercapacitor electrodes. **Journal of Energy Storage, 78**, 103421. https://doi.org/10.1016/j.est.2024.103421

6. Prakash, P., & Balaji, S. (2023). Phyllanthus emblica mediated green synthesis of metal oxide nanoparticles for electrochemical applications. **Materials Today: Proceedings, 72**, 3228–3235. https://doi.org/10.1016/j.matpr.2023.02.142

10. Conclusion

This research proposes an eco-friendly ZnO–NiO/bio-carbon nanocomposite synthesized using Phyllanthus emblica seed extract and coconut shell. The green approach aims to achieve high capacitance, superior energy density, and long cycle life, offering a sustainable pathway for next-generation supercapacitors.