Table: In Vitro Anti-Inflammatory Activity of Zinc Nanoparticles (Protein Denaturation Assay)

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Formulation and Therapeutic Evaluation of *Beta vulgaris*-Mediated Zinc Nanoparticles for the Management of Inflammatory Disorders

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INTRODUCTION & AIM

Inflammation is a natural defense mechanism, but its chronic persistence is associated with diseases such as arthritis, cardiovascular disorders, and neurodegeneration. Conventional therapies, though effective, often cause adverse effects and fail to provide long-term relief. Nanotechnology offers novel strategies to address these challenges, with zinc nanoparticles (ZnNPs) showing particular promise due to their biocompatibility, antioxidant, and immunomodulatory properties. However, traditional synthesis methods for ZnNPs are often costly and environmentally unsafe.

Green synthesis using plant resources provides a sustainable alternative, with phytochemicals acting as natural reducing and stabilizing agents. Beta vulgaris (beetroot), rich in polyphenols, flavonoids, and betalains, not only supports nanoparticle formation but also contributes to therapeutic potential through its strong antioxidant properties.

The present study aims to synthesize and characterize Beta vulgaris-mediated ZnNPs and to evaluate their anti-inflammatory efficacy, establishing a cost-effective and eco-friendly approach for managing inflammatory disorders.

METHOD

Preparation of Plant Extract

Fresh *Beta vulgaris* roots were washed, shade-dried, powdered, and boiled (20 g) in 200 mL distilled water for 30 minutes. The extract was filtered through Whatman No.1 paper and stored at 4 °C for further use.

Synthesis of Zinc Nanoparticles

Green synthesis of ZnNPs was carried out by mixing 50 mL of 1 mM zinc acetate dihydrate with 10 mL of *Beta vulgaris* extract under continuous stirring at 60 °C. The pH was adjusted to 8.0 using 0.1 M NaOH. A change in color indicated nanoparticle formation. The mixture was centrifuged at 12,000 rpm for 20 minutes, washed with distilled water and ethanol, and dried at 60 °C to obtain powdered ZnNPs.

Characterization

ZnNPs were characterized by UV–Vis spectroscopy (200–800 nm) to confirm nanoparticle formation. FTIR spectra (4000–400 cm^{-1}) were recorded to identify functional groups involved in reduction and stabilization. Morphology and size distribution were analyzed by Scanning Electron Microscopy (SEM), and the polydispersity index (PDI) was determined to assess uniformity.

Anti-Inflammatory Evaluation

Anti-inflammatory activity was assessed using protein denaturation and nitric oxide (NO) scavenging assays. Diclofenac and ascorbic acid served as standards, respectively. Percentage inhibition was calculated, and all experiments were conducted in triplicate. Data were expressed as mean ± SD and analyzed using one-way ANOVA, with $p < 0.05$ considered significant.

RESULTS & DISCUSSION

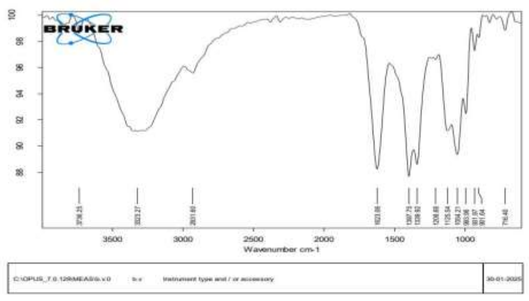

Figure 1. FTIR spectrum of *Beta vulgaris* aqueous extract showing characteristic peaks corresponding to functional groups such as –OH (phenols, alcohols), C=O (carbonyl compounds), and C–O (flavonoids, glycosides), indicating the presence of phytochemicals responsible for reduction and stabilization.

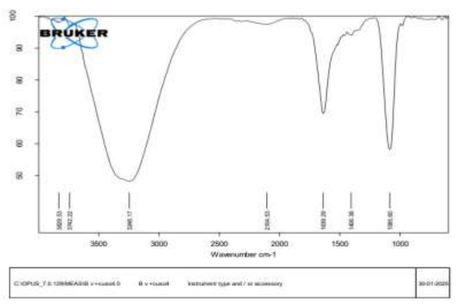

Figure 2. FTIR spectrum of *Beta vulgaris*-mediated zinc nanoparticles showing shifts in major functional groups, confirming interaction of phytoconstituents with zinc ions and successful stabilization of nanoparticles without drug–excipient incompatibility.

Formulation	Inhibition of Protein Denaturation (%)	Concentration (µg/mL)
F1	68.5%	100
F2	74.8%	100
F3	70.4%	100
F4	89.6% (Highest)	100
F5	76.3%	100

Formulation F4 demonstrated maximum inhibition (89.6%), suggesting superior anti-inflammatory potential, while other formulations exhibited moderate activity at 100 µg/mL.

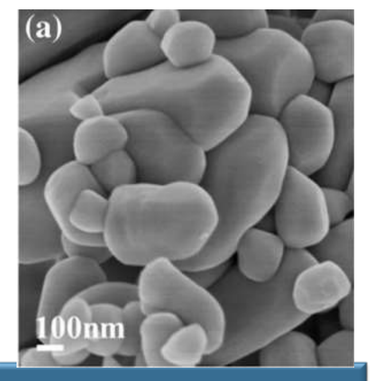

Figure 3. SEM image of *Beta vulgaris*-mediated zinc nanoparticles at 100 nm scale. The particles exhibited irregular to spheroidal morphology with sizes ranging from 30–120 nm. Moderate agglomeration was noted, typical of metal oxide nanoparticles, indicating successful synthesis and stabilization by phytoconstituents.

CONCLUSION

Beta *vulgaris*-mediated zinc nanoparticles showed promising anti-inflammatory activity, offering a green, cost-effective therapeutic approach for managing inflammatory disorders.

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