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Green Synthesis of Manganese Dioxide Nanoparticles and Their Effect on Sesbania grandiflora Seed Germination

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INTRODUCTION

Nanotechnology works with very small materials, usually between 1 and 100 nm. At this size, materials can show useful physical, chemical, and biological properties. In agriculture, nanomaterials are being explored for better nutrient use, crop protection, and plant growth. Green synthesis is a simple and eco-friendly approach in which plant extracts provide natural compounds that help in the formation and stabilization of nanoparticles.

Manganese is an important micronutrient for plants. Therefore, manganese dioxide (MnO_2) nanoparticles may be useful in agriculture when used carefully. In this study, MnO_2 nanoparticles were prepared using orange (Citrus x sinensis) peel extract, and their effect on the germination and seed vigour of Sesbania grandiflora was studied.

Objectives

- To synthesize MnO_2 nanoparticles using Citrus x sinensis peel extract through a green and sustainable route.
- To characterize the synthesized nanoparticles using FT-IR, XRD, SEM, EDAX, TGA, and DSC.
- To evaluate the effect of MnO_2 nanoparticles on the germination and seed vigour of Sesbania grandiflora seeds.

Preparation of Citrus x sinensis Peel Extract

- Fresh Citrus x sinensis fruits were collected locally from Heraheri village, Gurugram, Haryana.
- The peels were separated, washed with tap and distilled water, sun-dried, and ground into a fine powder.
- Twenty grams of peel powder was heated with 250 mL distilled water for 30 minutes.
- The mixture was cooled, filtered twice through Whatman filter paper, and the aqueous extract was stored under sterile conditions for further use.

Green Synthesis of MnO_2 Nanoparticles

- 100 mL of 0.1 M manganese sulfate monohydrate ($MnSO_4 \cdot H_2O$) solution was prepared.
- 50 mL of Citrus x sinensis peel extract was added dropwise under continuous stirring.
- A brown colour indicated the initiation of nanoparticle formation.
- The pH was adjusted using 0.1 M NaOH, followed by heating at 70 °C for 2 hours with constant stirring.
- The brown precipitate was collected by centrifugation, filtered, washed with double-distilled water and ethanol, dried, and gently ground to obtain MnO_2 nanoparticles.

Characterization and Key Findings

Characterization

- FT-IR spectroscopy: recorded to identify functional groups and Mn–O vibrations.
- X-ray diffraction (XRD): used to investigate the crystalline phase and structural characteristics.
- Scanning electron microscopy (SEM): used to study nanoparticle morphology and surface features.
- Energy-dispersive X-ray analysis (EDAX): used to determine elemental composition and distribution.
- Thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC): used to study thermal stability and phase transitions.

What Did We Find?

FT-IR analysis showed broad absorption bands at 3187, 1583, 1396, and 995 cm^{-1}. Bands in the 800–400 cm^{-1} region, including peaks near 589, 662, and 475 cm^{-1}, were associated with Mn–O and O–Mn–O vibrations, supporting MnO_2 formation. XRD peaks at approximately 11.6°, 31°, 37°, 44°, and 51.5° were assigned to crystal planes of the α-MnO_2 phase. The broad and weak peaks indicated a highly amorphous character with crystalline regions dispersed in an amorphous matrix. SEM observations revealed predominantly spherical to irregular nanoparticles with a rough surface texture and limited aggregation. EDAX confirmed the presence of manganese, oxygen, and carbon, with the reported atomic percentages of 21.84%, 47.57%, and 30.59%, respectively. TGA revealed major weight-loss stages from 25–100 °C, 100–350 °C, and around 350–400 °C. The first stage was associated mainly with loss of residual moisture, while later changes were linked with decomposition of organic components and manganese oxide phase transitions. DSC results further supported thermal changes observed in the TGA profile.

Effect on Seed Germination: - Sesbania grandiflora seeds were soaked overnight in distilled water before treatment. Two groups were prepared under identical laboratory conditions: a control group treated with distilled water and a treatment group exposed to an aqueous MnO_2 nanoparticle solution. Germination was monitored for 7 days.

Set of Seeds	Seeds Used	Vigour Seeds	Vigour (%)
S. grandiflora (Control, distilled water)	10	4	40%
S. grandiflora (MnO_2 NPs treatment)	10	8	80%

A clear difference was seen between the two groups. In the MnO_2-treated group, 8 out of 10 seeds germinated, giving 80% seed vigour. In the control group, only 4 out of 10 seeds germinated, giving 40% seed vigour.

Practical Recommendations

- Green synthesis using plant waste such as citrus peel offers a simple and eco-friendly route for nanoparticle preparation.
- MnO_2 nanoparticles showed a positive association with seed vigour in Sesbania grandiflora under the reported experimental conditions.
- Nanoparticle concentration, plant species, and exposure conditions should be optimized before wider agricultural application.
- Further studies should examine seedling growth, long-term plant responses, soil interactions, and environmental safety.

CONCLUSION

Citrus x sinensis peel extract successfully served as a biogenic reducing and stabilizing medium for the eco-friendly synthesis of MnO_2 nanoparticles. The synthesized material was characterized by FT-IR, XRD, SEM, EDAX, TGA, and DSC. The analyses supported the formation of manganese dioxide nanoparticles with α-MnO_2-related structural features and nanoscale morphology.

The seed germination study showed an improved response in the MnO_2 nanoparticle-treated Sesbania grandiflora seeds. The treated group exhibited 80% seed vigour compared with 40% in the control group. These findings suggest the potential of MnO_2 nanoparticles as nanopriming or agricultural-support materials, while emphasizing the need for further optimization and safety assessment.

Simple Take-Home Messages

- Use of plant-based materials can support greener methods for preparing useful nanomaterials.
- MnO_2 nanoparticles may influence seed germination and early seed vigour.
- The reported treatment showed better germination performance than the distilled-water control.
- Field-level use should only follow proper dose optimization and environmental evaluation.

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