Magnesium, zinc and copper nutrient nanoparticles infused sodium alginate-carboxymethyl cellulose based nano-hybrids as an efficient slow release fertilizer

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Abstract

According to the United Nations, Sustainable Development Goal 2 is to "create a world free of hunger by 2030." Slow release fertilizer is a promising method for controlling fertilizer usage and increasing agricultural productivity. Recent scientific advances in the agricultural field offer a significant promise in the usage of both the nanotechnology and slow release concepts simultaneously. This study attempts a slow release nano-formulation infused with the macronutrient magnesium and the two micronutrients copper and zinc. Nanomaterial characteristics were obtained by adding Mg, Zn, and Cu nutrients in their nano oxide forms while the nanoparticles(NPs) were loaded into a sodium alginate-carboxymethyl cellulose (SA-CMC) matrix to achieve the slow release property. Nanoparticles synthesized via sol gel method were sonicated with SA-CMC composite which was then cross-linked with Ca^{2+} to generate the hydrogel beads. The oxide nanoparticles were characterized by Powder X-ray Diffraction (PXRD), Fourier Transform Infrared (FTIR) spectroscopy, Raman spectroscopy, and Scanning Electron Microscopy (SEM). The average particle sizes for MgO, CuO, and ZnO nanoparticles examined by Image J software were recorded as 110, 220, and 285 nm respectively. The distribution of nutrients over the SA-CMC matrix were elaborated by the SEM while the FTIR spectroscopy demonstrated the creation of Ca^{2+} crosslinks. According to the AAS data, Zn, Mg, and Cu content percentages were recorded as 0.9%, 1.17%, and 0.15% w/w, respectively. Nutrient release investigation conducted using AAS in a water medium with a pH of 7.2 showed that 11.23%, 22.73%, and 3.03% of Zn, Mg, and Cu had released gradually over a period of 11, 6, and 6 days respectively. The Mung bean trial conducted exhibited significant increases in both plant height and the quantity of pods from the plants treated with the nano-hybrid fertilizer.

Introduction

The impending food crisis is a serious issue that the entire globe is about to encounter. The combination of slow release fertilizer technology with nanotechnology yields more effective fertilizer systems that increase the agricultural output. Therefore, in this study, a fertilizer formulation created by adding MgO, ZnO, and CuONPs to SA-CMC hydrogel beads are evaluated using both nanotechnology and slow release fertilizer principles. SA and CMC are commonly used polysaccharides for hydrogel delivery systems in agriculture due to the availability of OH and COOH groups which create the hydrophilic nature through the formation of hydrogen bonds needed to form the hydrogel three-dimensional structure. By crosslinking with cations, SA-CMC composite can be created into beads that are filled with nutritional particles. In this study, the plant nutrient nanoparticles are combined with the polymer composite and cross-linked with metal cations including Ca^{2+}. The SA-CMC composite in the growth media absorbs water and expands, allowing the dissolution of the nanoparticles inside the bead in water. The water then diffuses to the growing medium with the dissolved nutrients, where the plants take up the nutrients.

Methodology

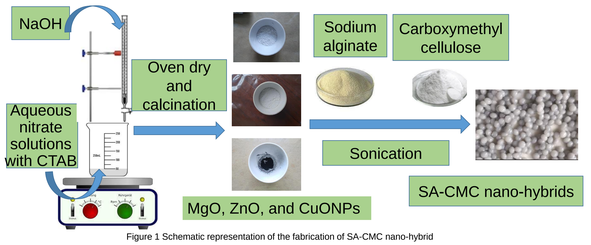
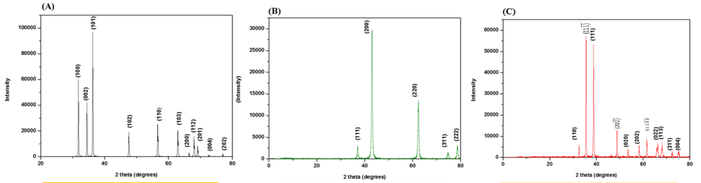


Figure 1 Schematic representation of the fabrication of SA-CMC nano-hybrid

PXRD analysis of NPs



JCPDS card No. = 36-1451 | JCPDS card No. = 78-0430 | JCPDS card No. = 48-1548

Average crystallite size according to Scherer equation = 85 nm | Average crystallite size according Scherer equation = 22 nm | Average crystallite size according to Scherer equation = 43 nm

Figure 2 PXRD pattern of (A)ZnONPs (B)MgONPs (C) CuONPs

FTIR analysis of NPs

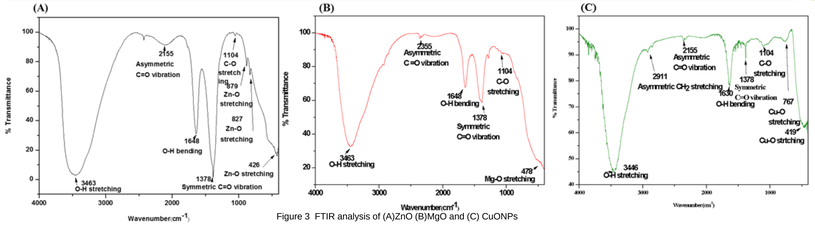


Figure 3 FTIR analysis of (A)ZnO (B)MgO and (C) CuONPs

Raman analysis of NPs

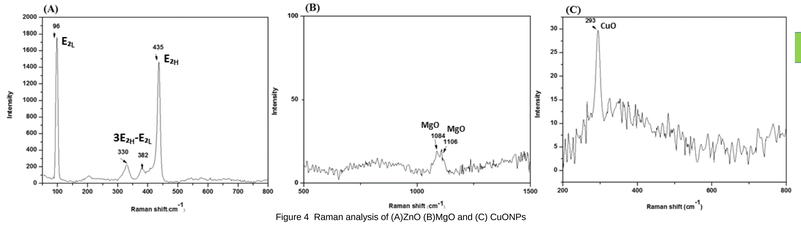
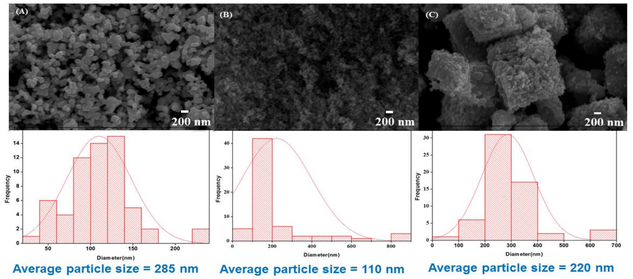


Figure 4 Raman analysis of (A)ZnO (B)MgO and (C) CuONPs

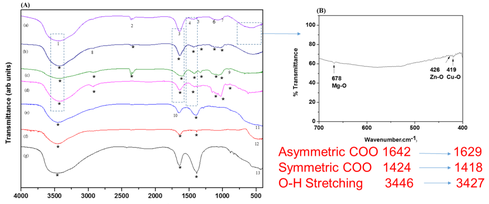
SEM analysis of NPs



Average particle size = 285 nm | Average particle size = 110 nm | Average particle size = 220 nm

Figure 5 SEM images and particle size distribution of (A)ZnO (B)MgO and (C) CuONPs

FTIR analysis of MgO, ZnO, and CuONPs loaded SA-CMC beads



Asymmetric COO 1642 → 1629
Symmetric COO 1424 → 1418
O-H Stretching 3446 → 3427

Fig 6 FTIR spectrum of (A) (a) MgO, ZnO, and CuONPs loaded SA-CMC beads (b) Ca cross-linked SA-CMC (c) CMC (d) SA

(e) MgONPs (f) CuONPs (g) ZnONPs in the range 4000 cm^{-1} to 400 cm^{-1}

(B) FTIR spectrum of MgONPs, ZnONPs, and CuONPs loaded SA-CMC beads in the range 700 cm^{-1} and 400 cm^{-1}

PXRD analysis of MgO, ZnO, and CuONPs loaded SA-CMC beads

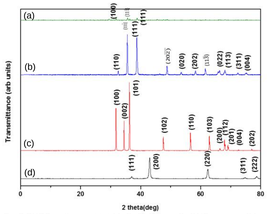


Fig 7 PXRD patterns of (a) MgO, ZnO, and CuONPs loaded SA-CMC beads (b)CuONPs (c)ZnONPs (d)MgONPs

SEM analysis of MgO, ZnO, and CuONPs loaded SA-CMC beads

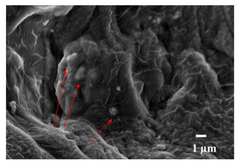
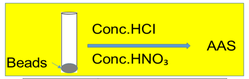


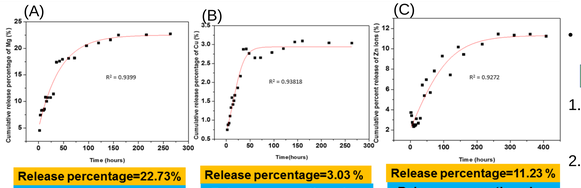
Fig 8 SEM image of MgO, ZnO, and CuONPs loaded SA-CMC beads

Total Mg, Zn, and Cu content determination



Nutrient	Total nutrient (%)
Mg	1.17 ± 0.36
Zn	0.89 ± 0.16
Cu	0.15 ± 0.15

Nutrient release behaviour in water at pH 7.2



Release percentage=22.73% Release was continued up to 6 days | Release percentage=3.03 % Release was continued up to 6 days | Release percentage=11.23 % Release was continued up to 11 days

Fig 9 Cumulative release percentage of (A) Mg (B) Cu (C) Zn versus time curves of MgO, ZnO, and CuONPs loaded SA-CMC beads at pH 7.2

Plant trial for evaluating the fertilizer efficiency

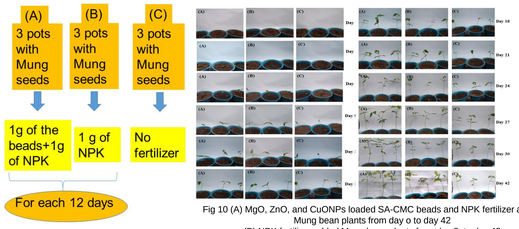


Fig 10 (A) MgO, ZnO, and CuONPs loaded SA-CMC beads and NPK fertilizer added Mung bean plants from day o to day 42

(B) NPK fertilizer added Mung bean plants from day 0 to day 42

(C) Mung bean plants without MgONPs , ZnONPs, and CuONPs loaded SA-CMC beads and NPK fertilizer from day 0 to day 42

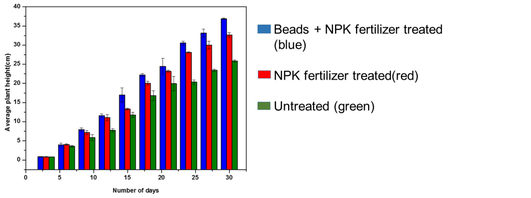


Fig 11 Average plant height of mung bean studied for 30 days in various setups: MgO, ZnO, and CuONPs loaded SA-CMC beads with NPK fertilizer treated (blue) , NPK fertilizer treated(red) untreated (green)

	Beads with NPK treated plants	NPK treated plants	Untreated Mung bean plants
Average number of pods	4	1	0

Conclusion

- **The ionotropic gelation technique was a successful technique to fabricate hydrogel beads loaded with plant nutrient NPs which was proven upon FTIR analysis.**
- **The fabricated nutrient-infused nano hybrids had Zn, Mg, and Cu content percentages of 0.9%, 1.17%, and 0.15% w/w, respectively.**
- **A slow release of nutrients was observed where 11.23%, 22.73%, and 3.03% of the total Zn, Mg, and Cu were released over a period of 11, 6, and 6 days, respectively.**
- **Significant increases in the plant height and the quantity of pods were observed in the plants that received the slow-release nano-hybrid fertilizer treatment.**
- **Finally, it is obvious that the prepared hydrogel beads have slow-releasing properties while efficiently supplying the nutrients needed by the plants.**

References

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