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ANALYTICAL SPECTROSCOPIC CHARACTERIZATION OF GREEN CHITOSAN/COPPER NANOCOMPOSITES FOR FOOD PACKAGING APPLICATIONS

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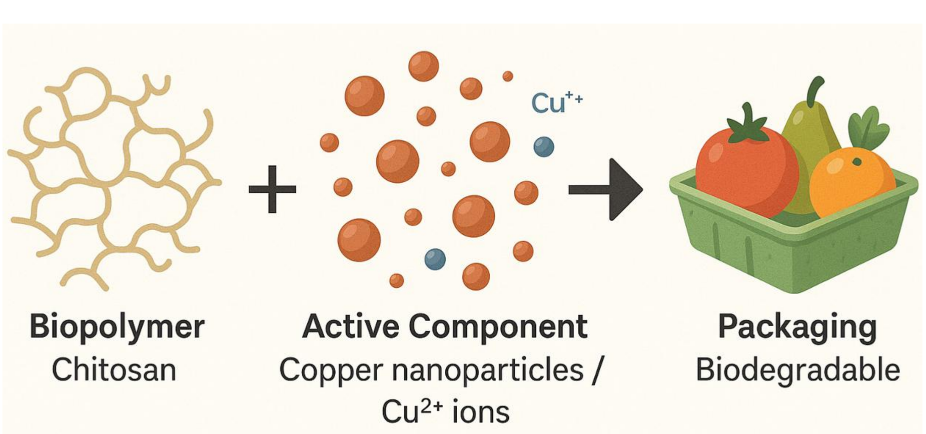
INTRODUCTION & AIM

The development of biodegradable and bio-based functionalized packaging materials addresses **two key challenges**:

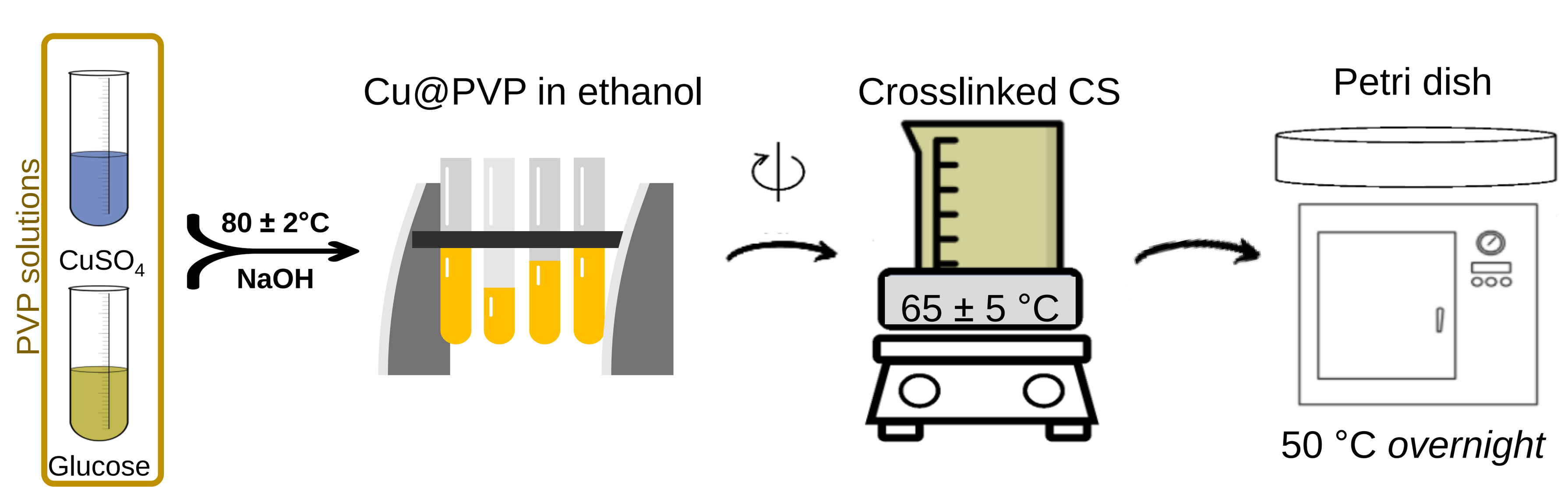
- **Reducing the environmental impact** of agrifood waste, linked mainly to fungal contamination and the widespread use of non-biodegradable polymers;
- **Extending shelf life** while minimizing the use of post-harvest chemical treatments that may contribute to the emergence of antimicrobial resistance (AMR).



In this study, the bio-based polymer chitosan (CS), extracted from crustacean shells and insect cuticles, was functionalized with copper sub-microparticles. Both chitosan and copper are known for their antimicrobial properties, primarily through interactions with microbial cell membranes and the generation of reactive oxygen species (ROS), thus lowering the risk of AMR development.

The objective of this research was to highlight the synergistic and enhanced antimicrobial performance achieved through this composite film approach.

METHOD



Copper particle synthesis[1],[2] was carried out using a polyvinylpyrrolidone (PVP) solution as a solvent for both the copper precursor (copper sulfate pentahydrate) and the reducing agent, glucose. PVP plays a dual role: it prevents copper oxidation, thus eliminating the need for an inert atmosphere and simplifying the synthesis process, and acts as a capping agent (Cu@PVP), reducing particle aggregation, via steric hindrance, along with glucose oxidation by-products that contribute to the electrostatic stabilization of the colloidal dispersion.

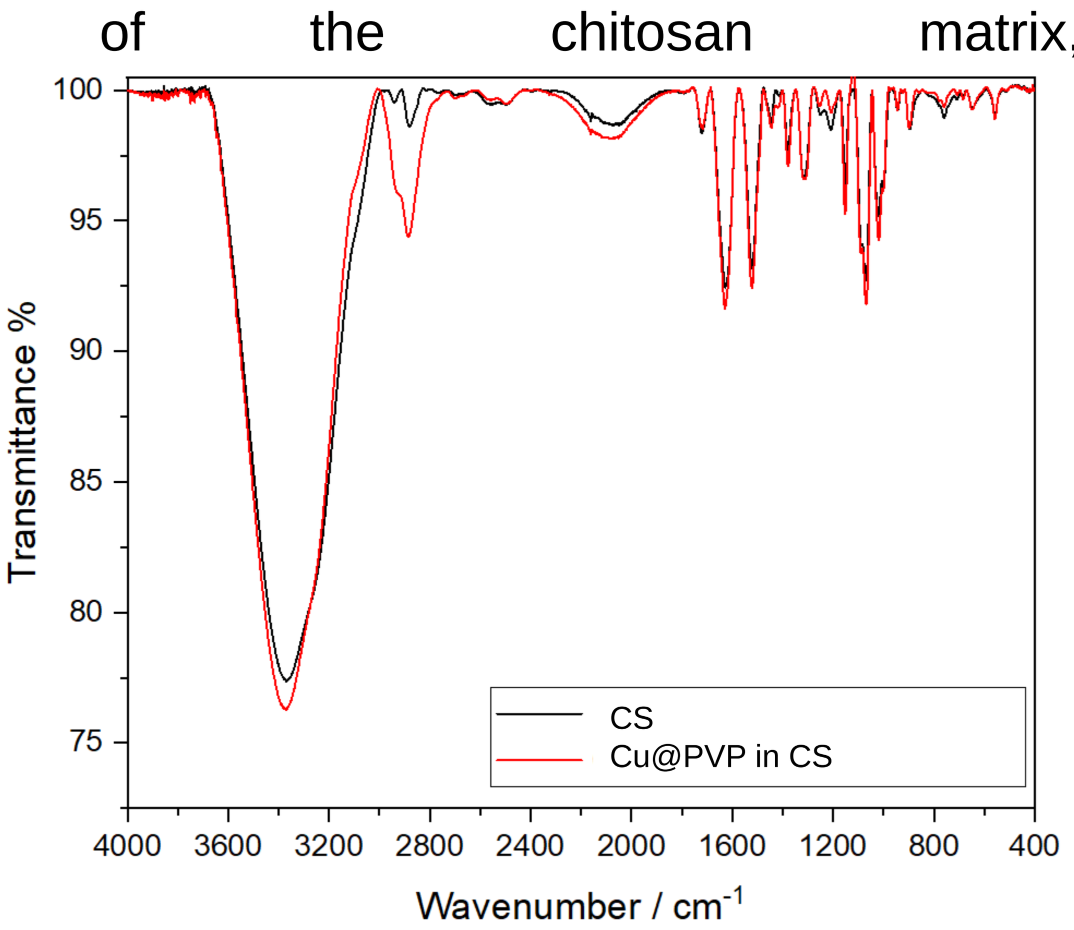
To minimize nanotoxicity, the average particle diameter was maintained above 200 nm. Therefore, PVP and glucose concentrations were varied individually to study their effect on particle size, copper oxidation state, and reaction kinetics, with the goal of reducing reagent use and synthesis time for a more sustainable approach. After purification from synthesis by-products, Cu@PVP particles were suspended in ethanol.

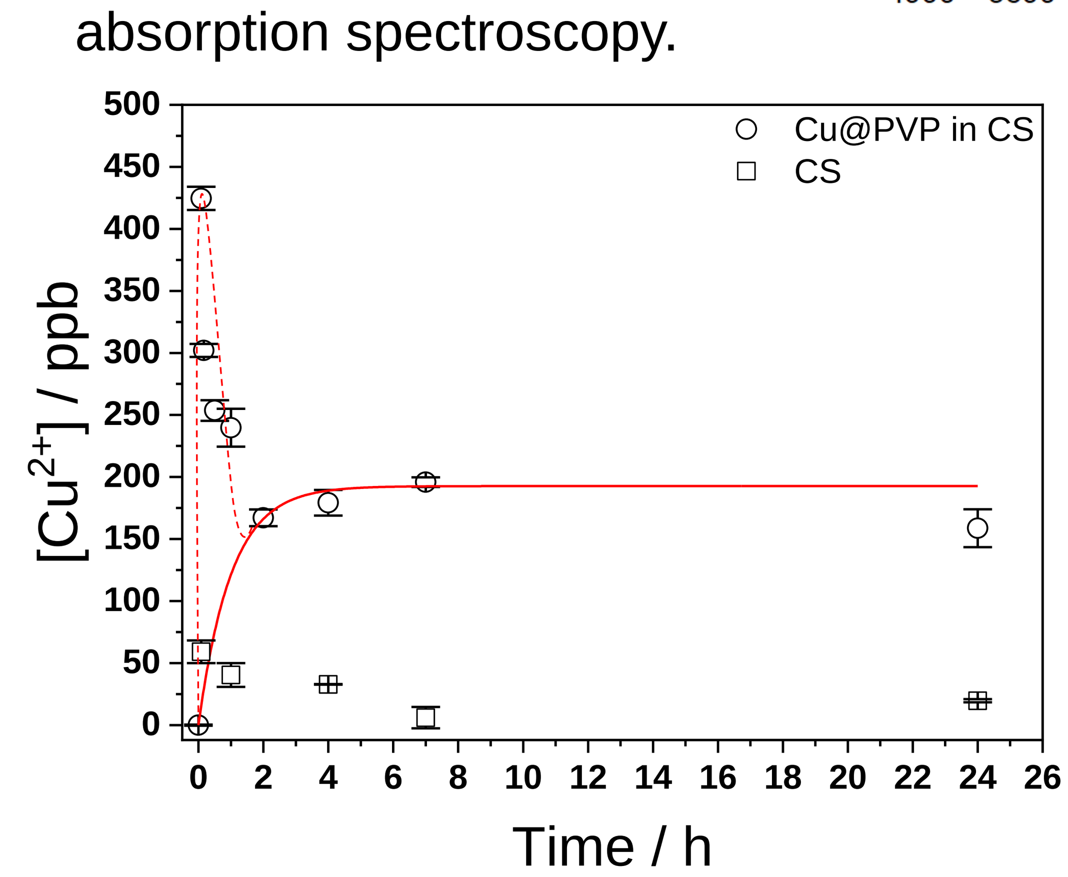
Self-standing chitosan/copper nanocomposite films[1],[2] were obtained by adding the Cu@PVP suspension to a crosslinked chitosan solution, then casting and drying it overnight in a heated environment to promote solvent evaporation. The crosslinking process was performed by adding glutaraldehyde and tannic acid as crosslinking agents, under continuous stirring at (65 ± 5)°C, using a 1%$_{v/v}$ acetic acid solution as the solvent.

RESULTS & DISCUSSION

Rheological characterization[1] of the crosslinked chitosan (CS) solution revealed distinct behavior between formulations with and without Cu@PVP. The polymer concentration was therefore optimized to preserve films' torsional rheological characteristics and to minimize water uptake.

ATR-FTIR spectra[1] of both bare CS and Cu@PVP/CS films revealed the characteristic signals of the chitosan matrix, indicating that the chemical environment of the polymer remains unaltered upon Cu@PVP embedding. To assess the release profile, the **Cu^{2+} ions kinetic release**[1] was studied by immersing the composite films in a contact medium for varying durations and analyzing the samples via electrothermal atomic absorption spectroscopy.





The results demonstrated a controlled and sustained release of the antimicrobial agent at effective concentrations.

Two overlapping trends were identified: an initial supersaturation of cupric ions within the first hour, leading to precipitation of Cu(II) species, followed by a plateau at 173 ± 9 ppb, suggesting a pseudo-first-order kinetic profile. These features set the foundation for ***in vitro* growth inhibition tests**[1] against three common fungi associated with agrifood spoilage. The colony diameter was compared with control plates (growth medium only), CS films, and CS/Cu@PVP films. In all cases, plain CS films exhibited intrinsic antimicrobial activity, while the nanocomposite films showed enhanced inhibition, highlighting the synergistic effect between the polymer matrix and the copper-based additive.

	Control	CS	CS/Cu@PVP
Alternaria alternata	37.0 ± 1.2 mm	0.0 ± 0.5 mm	0.0 ± 0.5 mm
Botrytis cinerea	51 ± 5 mm	6.8 ± 0.8 mm	0.0 ± 0.5 mm
Colletotrichum acutatum	39.1 ± 0.9 mm	17.5 ± 0.9 mm	13.9 ± 0.5 mm

CONCLUSION

This innovative material could be used for the **production of biodegradable bags** and envelopes destined to the storage of fruits and vegetables, **extending the shelf-life** of these horticultural products.

REFERENCES

[1] d'Agostino et al., Food Chem., 2025, 464, 141823.
[2] d'Agostino et al LA CHIMICA E L'INDUSTRIA | ANNO IX | N° 2 | 2025, 10.17374