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Direct ink writing of hydroxyapatite based paste scaffolds for absorption-release of drug solutions

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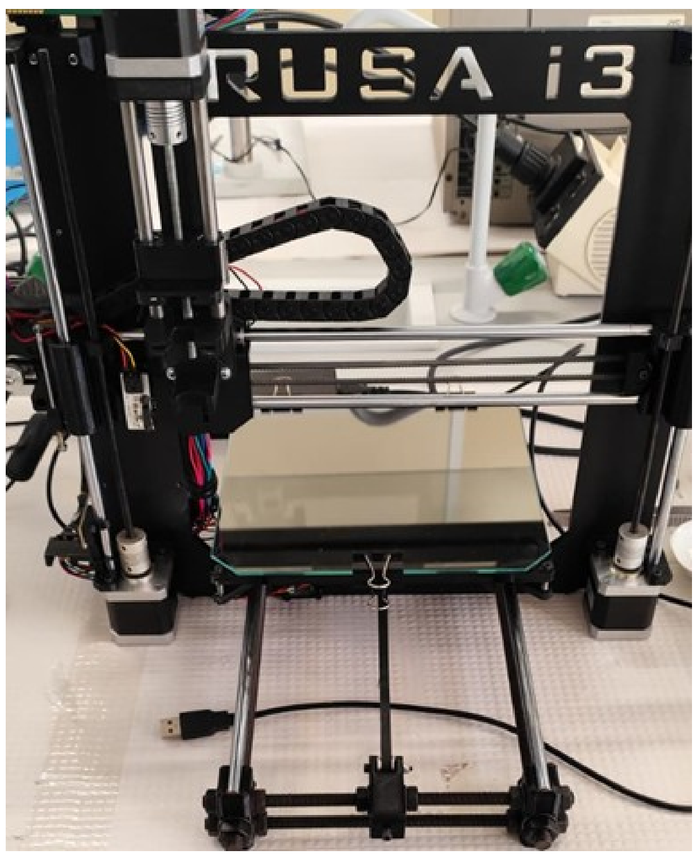
INTRODUCTION & AIM

The demand for new production processes, advanced materials, and innovative drug delivery applications has changed significantly in recent years. There is an increasing demand for the development of compounds and delivery systems with properties that enable the design of personalized medicines [1].



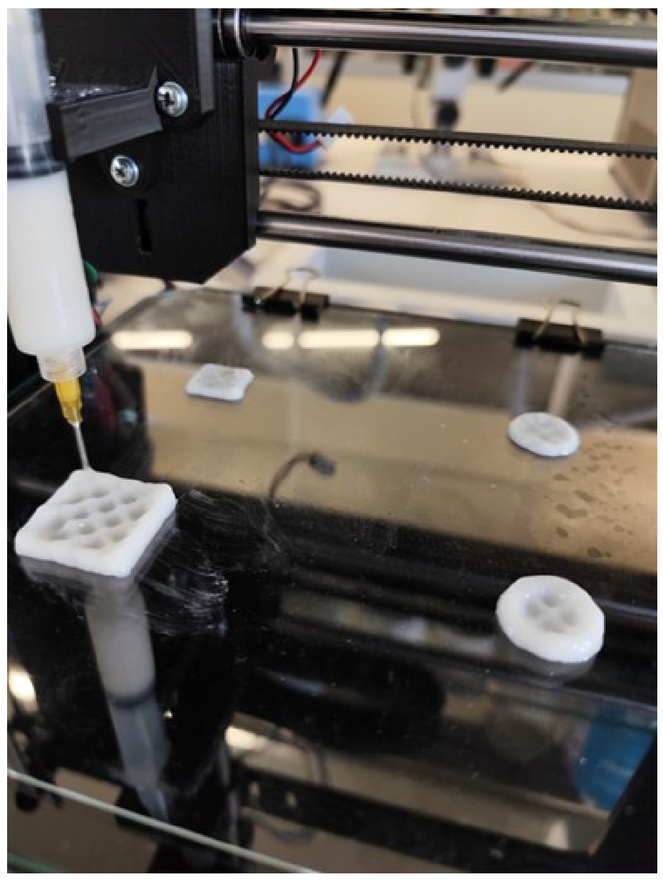
Three dimensional (3D) bioprinting, has emerged as a transformative technology that enables the fabrication of complex architectures with high reproducibility, low material waste, and the ability to integrate bioactive molecules directly into the printed structures.

This work explores the incorporation and controlled release of antibiotics through a matrix composed of biomaterials and focuses on developing and optimizing a hydroxyapatite based paste formulation suitable for Direct-Ink-Writing (DIW), for the production of stable and porous scaffolds capable of absorbing and releasing antibiotic solutions.

METHOD

The 3D printer used in this study was a **OpenSource RepRap 3D printer**, a highly modified Hephestos Prusa i3, which provided a low-cost alternative for easy maintenance, and modification [2].

Scaffold fabrication was carried out using a **original design syringe-based extrusion printing system enabling a continuous layer-by-layer deposition**, allowing the formation of well-defined structures. It also provides high precision and deposition control.



The **hydroxyapatite-based paste formulation consisted of 37.5 wt% hydroxyapatite, 38 wt% sucrose, 0.5 wt% sodium alginate, and 24 wt% water, optimized to achieve printability, mechanical stability, and antibiotic incorporation.**

After printing, the scaffolds were air-dried and subsequently impregnated with antibiotic solutions for antibacterial testing against *Escherichia coli* (Gram-negative) and *Staphylococcus aureus* (Gram-positive)

Analysis methods implemented

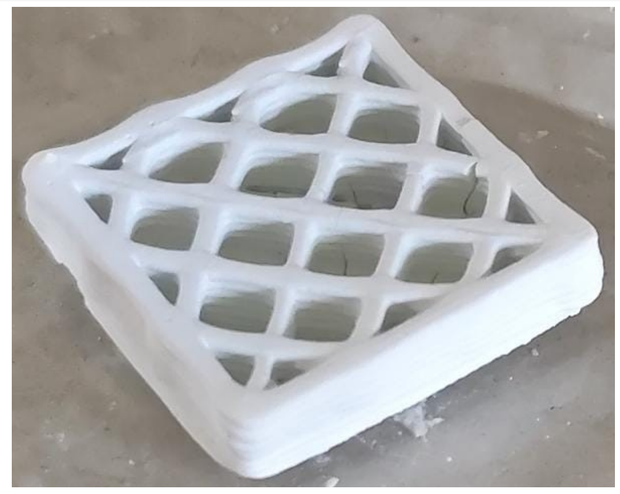
- **Fourier-transform infrared spectroscopy coupled with attenuated total reflectance (FTIR-ATR);**
- **Scanning electron microscopy (SEM);**
- **Microbiological antibacterial assays.**

These analyses allowed **a comprehensive assessment** of the structural and functional performance of the 3D printed scaffolds.

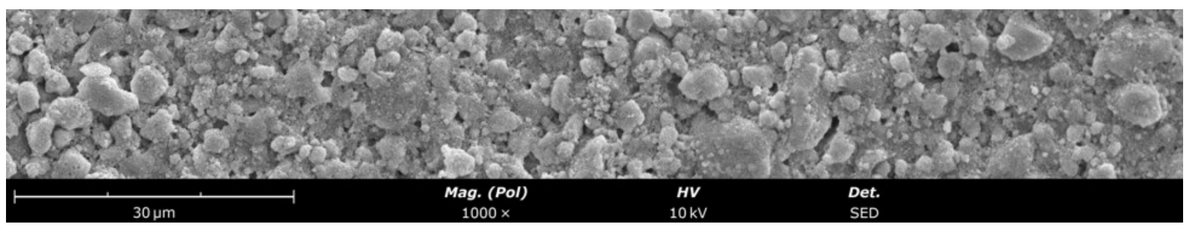
RESULTS & DISCUSSION

Hydroxyapatite-based paste
37.5% hydroxyapatite
38% sucrose
0.5% sodium alginate
24% water

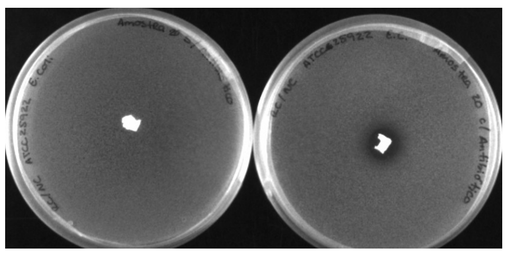
3D print parameters
layer height: 0.8 mm
line width: 1.6 mm
infill type: grid
infill density: 57%
dimensions (mm): 26x26x7



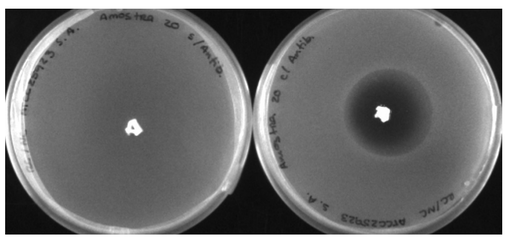
Granules of hydroxyapatite and sodium alginate of various sizes can be observed in SEM analysis. The use of a powder homogenizer could help achieve a more uniform particle size and distribution.



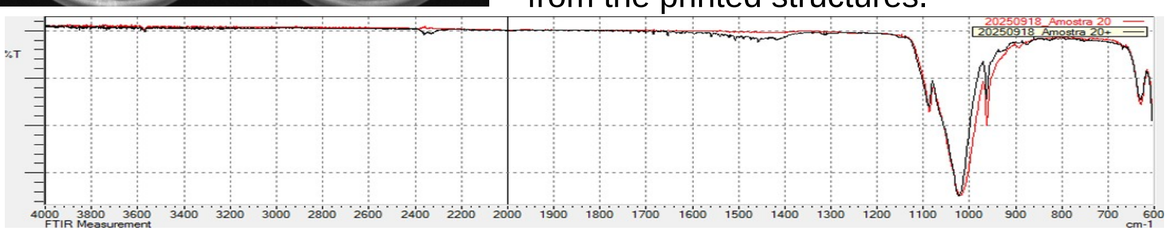
The **antibiotic** selected for **scaffold impregnation** was **sulfanilamide**. The compound was dissolved in ethanol (2.5% (m/v)). The scaffold was submerged in 10 mL of this solution for 45 min to attempt absorption of the antibiotic. The samples were exposed to bacterial environments to assess antibiotic release [3].



For ***E. coli*** **(Gram-negative) bacterial growth inhibition** was evident from the darker areas surrounding scaffolds impregnated with sulfanilamide.



For ***S. aureus*** **(Gram-positive), the difference between cultures with and without antibiotic was even more pronounced**, confirming a stronger inhibitory effect and successful drug release from the printed structures.



FTIR spectrum and vibrational bands
P–O bond at 963, 1019, and 1087 cm^{-1}; and 600 and 629 cm^{-1} (deformation modes); C–O bond band of sulfanilamide is superimposed on the hydroxyapatite vibrational spectra.

CONCLUSION

This study successfully developed a **hydroxyapatite-based paste suitable for DIW 3D printing**, producing porous, mechanically stable scaffolds. Impregnation with sulfanilamide **demonstrated effective antibiotic absorption and release, confirmed by microbiological assays, SEM, and FTIR analyses**.

REFERENCES

[1] Bastos, A. R., *et al* (2024). Hydroxyapatite/alginate/gellan gum inks with osteoconduction and osteogenic potential for bioprinting bone tissue analogues. International journal of biological macromolecules, 271(Pt2),132611. https://doi.org/10.1016/j.ijbiomac.2024.132611
[2] Prusa i3 Hephestos https://wiki.reprap.org/wiki/Prusa_i3_Hephestos; Marlin Firmware – Multi-Axis Robot Driver https://marlinfw.org (30/oct/2025).
[3] Tripathi, N., Zubair, M., & Sapra, A. (2025). Gram Staining. In *StatPearls*.

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