

## Abstract

# Integration of cellulose nanofibers in the formulation of PLA/HAp filaments: an alternative to their application as ECM

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The need for advanced biomimetic biomaterials is critical in tissue engineering due to the rising demand for bone grafts and the limitations of conventional methods [1]. In this context, the combination of bio-based nanocellulose matrix and hydroxyapatite (HAp) has garnered significant interest because of the complementary advantages these materials offer. Nanocellulose provides mechanical strength, flexibility, and biodegradability, while HAp contributes its bioactivity, biocompatibility, and osteoinductivity [2]. This study proposes a dual role of cellulose nanofibers (CNF) as a mechanical nano-reinforcement within the solid matrix and as a biomimetic supporter within a hydrogel phase for bone tissue engineering. CNF were obtained through an integral biorefinery process of agro-industrial by-products, aligning the fabrication with circular economy principles and sustainability goals. To produce advanced filaments, a colloidal route was developed to incorporate the CNF and HAp into a PLA matrix. The integration of CNF acts as a critical rheological modifier, significantly enhancing the process stability during fused filament fabrication (FFF). This is evidenced by a reduction in the coefficient of variation regarding mass flow, ensuring a highly consistent layer deposition that minimizes dimensional deviation relative to the nominal STL geometry. Furthermore, CNF enhances microstructural properties by creating a tailored porosity that increases the specific surface area. The 3D-printed scaffolds structural integrity and functional behavior were assessed through degradation assays, which revealed that the presence of CNF facilitates a sustained and enhanced release of calcium ions, a critical factor for triggering osteogenic signaling pathways. CNF exhibited a buffering capacity that mitigates the autocatalytic acidification typical of PLA degradation, thereby maintaining a physiological pH environment that optimized the conditions for bone ingrowth. Biological validation through cell viability studies confirmed the non-cytotoxic nature of scaffolds. The synergy between HAp and the waste-derived CNF provides a sustainable, high-performance alternative for bone tissue engineering.

### AUTHOR'S STATEMENT

L. Gallego is employed by COLFEED4Print S.L. All other authors state no conflict of interest. This research is supported by projects CPP2023-010820 and PDC2025-165071-I00, funded by MICIU/AEI/10.13039/501100011033 and "ERDF. A way of making Europe".

### REFERENCES

- [1] T. Strunk, F.M. Thieringer, N. Rohr, N. Sharma, Guided Bone Regeneration: A novel approach to 3D-printed biodegradable meshes, Transactions on Additive Manufacturing Meets Medicine 7 (2025) 2062–2062. <https://doi.org/10.18416/AMMM.2025.25062062>.
- [2] S. Berrahou, S. Latifi, S. Saoiabi, N. Abidi, S. Saoiabi, K. Azzaoui, G. Hanbali, S. Jodeh, B. Hammouti, R. Sabbahi, Hydroxyapatite–cellulose composites: properties, fabrication methods, and applications, Journal of Materials Science: Materials in Medicine 2026 37:1 37 (2026) 27–. <https://doi.org/10.1007/S10856-025-06993-1>.