

# A Sustainable Multifunctional Approach to Food and Pharmaceutical Packaging Using a Modified Tannin-Based Functional Additive

Klementina Pušnik Črešnar<sup>1,2\*</sup>, Laura Šantl<sup>2</sup>, Olivija Plohl<sup>1</sup>, Irena Ban<sup>2</sup>, Janja Stergar<sup>2</sup>, Lidija Fras Zemljič<sup>1</sup>

<sup>1</sup> University of Maribor, Faculty of Mechanical Engineering, Slovenia

<sup>2</sup> University of Maribor, Faculty of Chemistry and Chemical Engineering, Maribor, Slovenia

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Presenting author email: [\\*klementina.pusnik@um.si](mailto:klementina.pusnik@um.si)

## Abstract

The application of recycled polyolefins in high-value sectors such as food and pharmaceutical packaging is constrained by oxidative degradation and limited interfacial compatibility with functional additives. State-of-the-art stabilisation strategies for recycled polypropylene rely primarily on synthetic antioxidants and compatibilisers, which are effective but increasingly challenged by sustainability, regulatory, and environmental concerns. Bio-based functional additives—particularly natural polyphenols—have emerged as promising sustainable alternatives due to their multifunctional performance, including antioxidant, barrier, and compatibilisation effects [1]. Among these, tannins are plant-derived polyphenols that can improve mechanical performance and extend the functional lifetime of packaging materials through radical scavenging and other protective mechanisms [2]. The incorporation of tannins into polymer matrices has been demonstrated in flexible films exhibiting enhanced antioxidant activity and improved barrier performance for packaging applications [3].

The novelty of this work lies in the use of citric-acid-functionalised tannin (T-CA) as a dual-function bio-based functional additive that simultaneously enhances interfacial compatibility and antioxidant performance in recycled polypropylene matrices. In this study, a modified tannin-based functional additive was developed via citric acid functionalisation to overcome limitations associated with poor dispersion and weak interfacial adhesion in recycled polypropylene (PP-r). Tannin was chemically functionalised with citric acid to enhance its compatibility with PP-r by improving dispersion and interfacial interactions. The resulting T-CA was incorporated into PP-r by hot-melt extrusion (HME), providing a scalable and industry-relevant processing route.

Attenuated total reflection Fourier-transform infrared (ATR-FTIR) spectroscopy confirmed successful citric acid functionalisation of tannin, while thermogravimetric analysis (TGA) demonstrated enhanced thermal stability of T-CA. Changes in surface charge, assessed by zeta potential measurements supported by dynamic light scattering, indicated modified interfacial characteristics of the functionalised tannin. When incorporated into recycled polypropylene, differential scanning calorimetry (DSC) showed that T-CA did not adversely affect the melting or crystallisation behaviour of the polymer matrix, while TGA indicated improved thermal stability of the resulting composites. Antioxidant performance, evaluated using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay, confirmed that T-CA retained effective antioxidant activity after functionalisation and melt processing.

This approach offers a sustainable alternative to conventional synthetic additives and provides a viable pathway for upgrading recycled polyolefins toward multifunctional materials suitable for food and pharmaceutical packaging applications. Moreover, by combining waste-derived polymers with bio-based functional additives, this strategy supports circular material design and reduces reliance on fossil-based stabilisers in high-value packaging applications.

## References

Marturano, V., Cerruti, P., Ambrogi, V., & Gorrasi, G. (2023). Bio-based functional additives for sustainable polymer materials: A critical review. *Progress in Polymer Science*, 138, 101646. <https://doi.org/10.1016/j.progpolymsci.2023.101646>

Vera, R., Álvarez, A., & Gutiérrez, T. J. (2023). Tannins as multifunctional additives in food packaging materials: Antioxidant, antimicrobial and barrier properties. *Trends in Food Science & Technology*, 132, 180–195. <https://doi.org/10.1016/j.tifs.2022.12.012>

Ferri, J. M., Samper, M. D., García-Sanoguera, D., & Balart, R. (2021). Polyphenol-based antioxidant additives for active packaging applications: Tannin-containing polymer systems. *ACS Applied Materials & Interfaces*, 13(12), 14545–14556. <https://doi.org/10.1021/acsami.0c22314>