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

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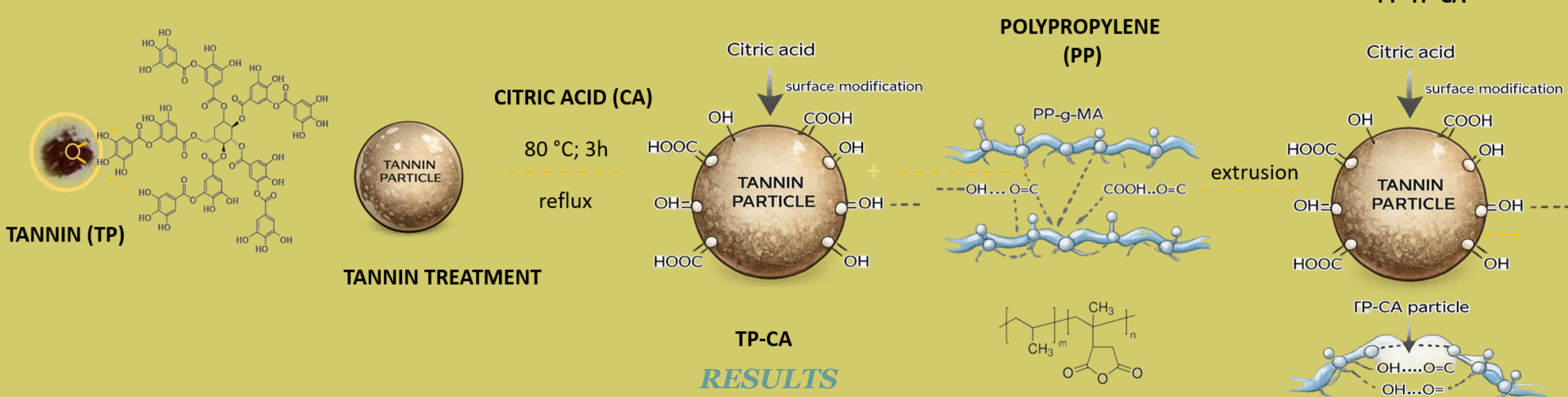
INTRODUCTION

Polymers play a decisive role in blister pharmaceutical packaging, as they protect drug products from external factors that may compromise their stability, safety, and quality throughout their shelf life. Blister materials rely on multilayer structures combining polymers such as polyvinyl chloride (PVC), polyvinylidene chloride (PVDC), polyethylene terephthalate (PET), and polypropylene (PP) with aluminum to achieve high barrier performance; however, their complex composition limits recyclability. In response, research is shifting toward monomaterial polyolefins, particularly PP, which offer improved recyclability but primarily act as passive barriers. Conventional stabilization using low-molecular-weight antioxidants is limited by migration and reduced long-term efficiency, prompting the development of bio-based, non-migratory alternatives. Bio-based additives, particularly natural polyphenols such as tannins (TP), offer a promising alternative due to their antioxidant, barrier, and compatibilising functions [1]. However, their application in PP is restricted by poor dispersion and weak interfacial adhesion.

In this work, citric-acid-functionalised tannin (TP-CA) is introduced as a multifunctional additive to improve compatibility, antioxidant, and UV-light performance in PP. Functionalisation enhances dispersion and interfacial interactions, while melt processing via hot-melt extrusion ensures industrial relevance. Structural and thermal analyses confirm successful modification and stability, while antioxidant testing demonstrates retained activity after processing. This approach provides a sustainable pathway for upgrading recycled polyolefins into multifunctional materials suitable for advanced pharmaceutical packaging applications.

Extrusion of Multifunctional PP Composites with CA-Modified Tannin



RESULTS

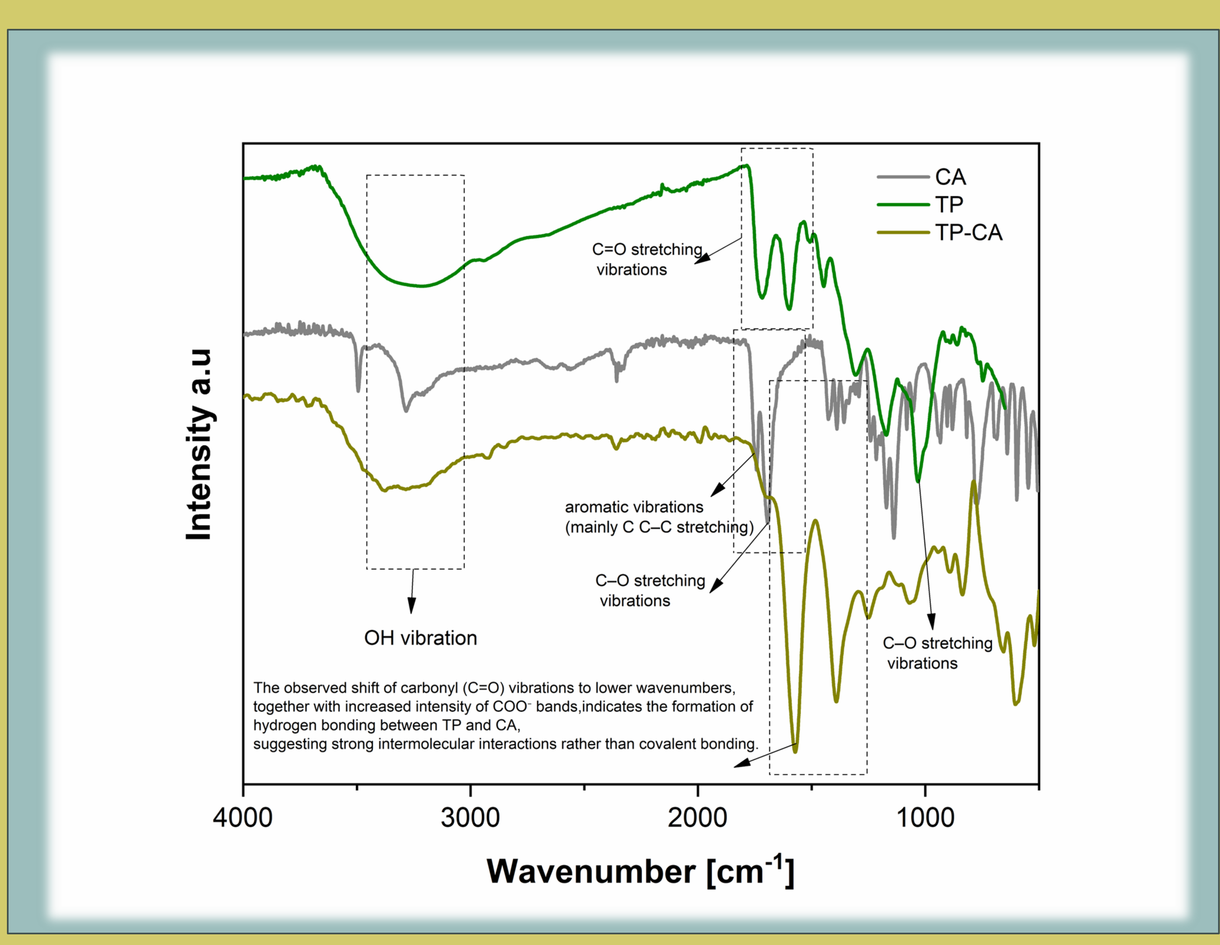
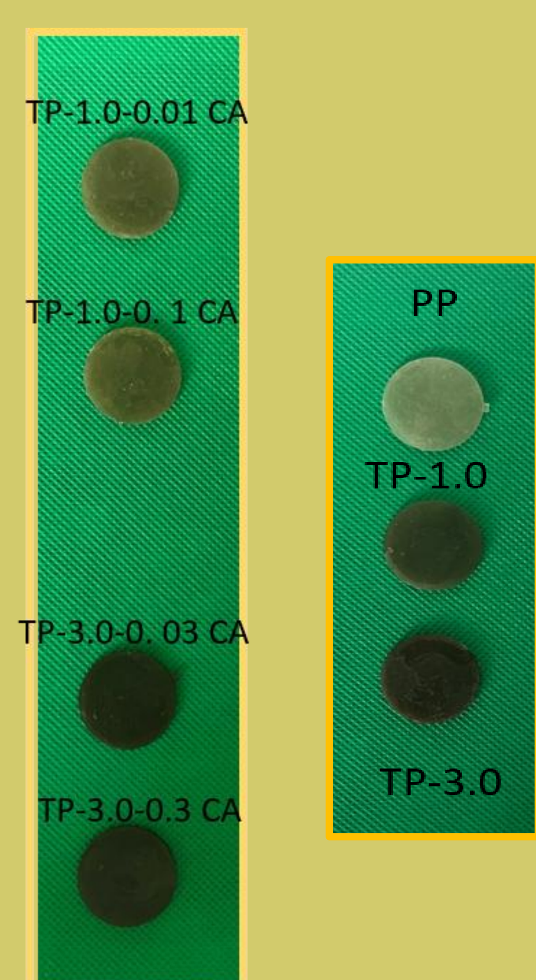


Figure 1. ATR-FTIR spectra of CA, TP, and TP-CA showing characteristic bands and shifts of C=O vibrations, indicating hydrogen bonding between TP and CA.



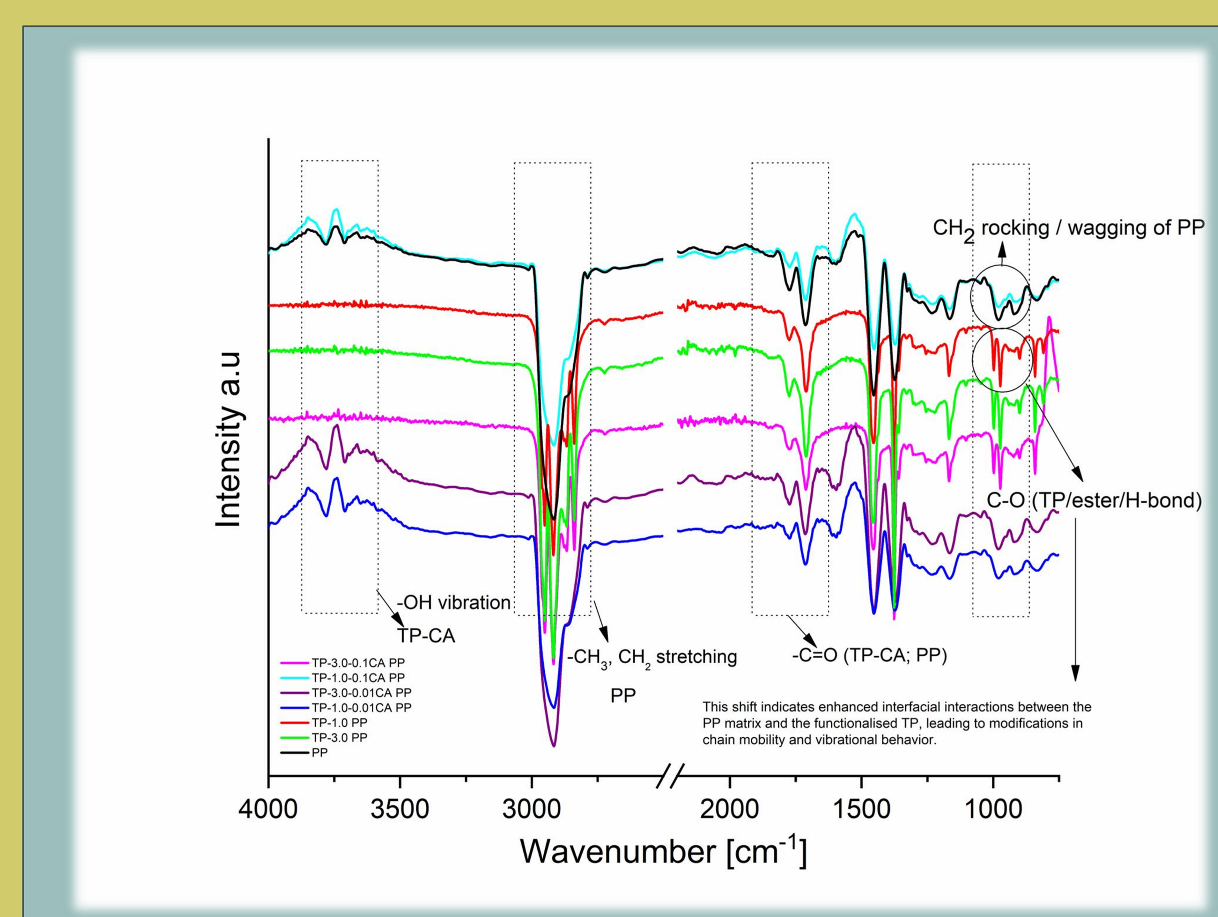


Figure 2. ATR-FTIR spectra of PP and composites with TP and TP-CA, showing characteristic PP bands and additional O–H and C=O signals, indicating TP incorporation and enhanced interfacial interactions after functionalisation.

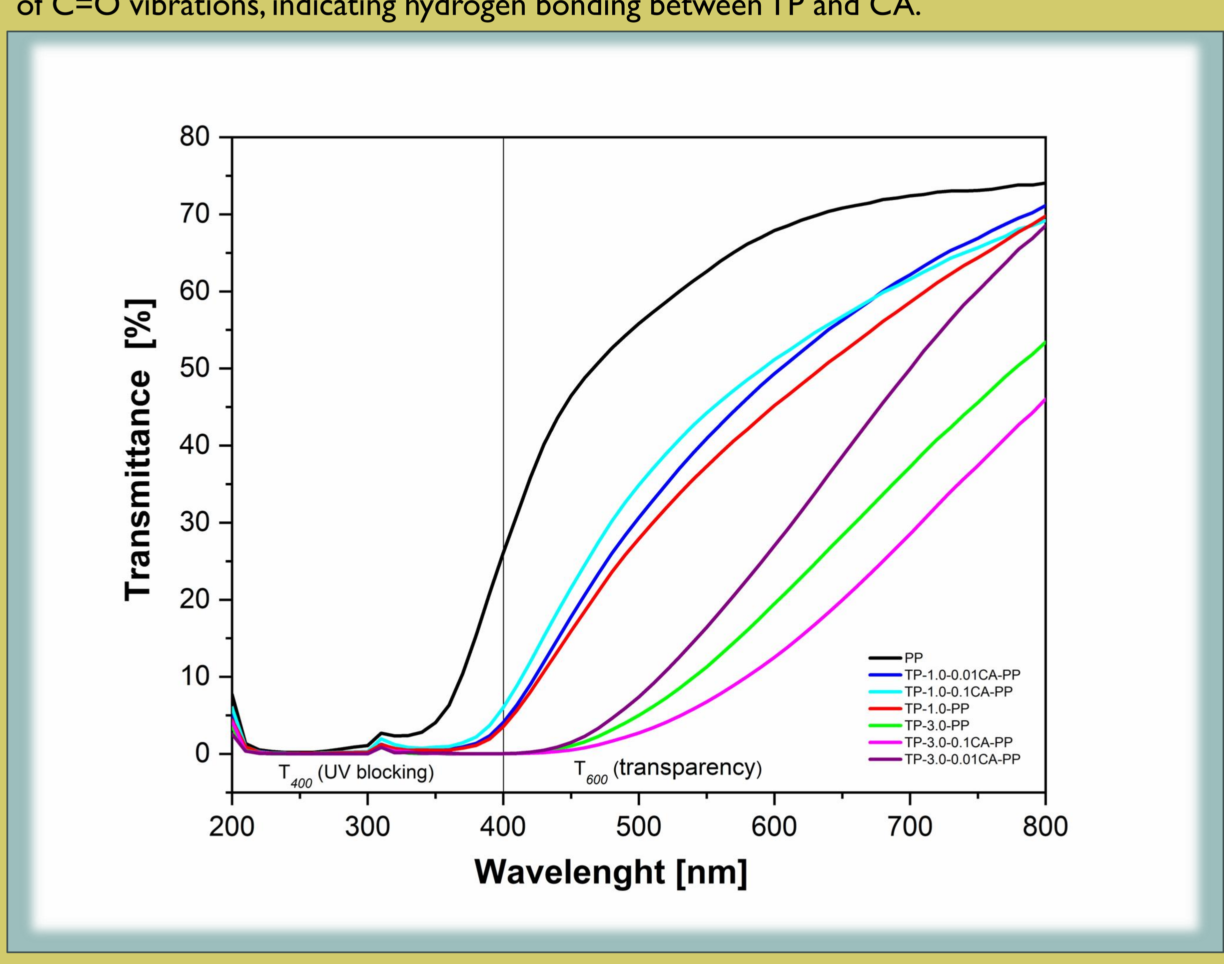


Figure 3. UV–Vis transmittance spectra of PP and composites with TP and TP-CA. Transmittance decreases with filler loading, especially in the UV region (T_{400}), while visible transparency (T_{600}) is reduced. TP-CA shows enhanced UV-blocking due to improved dispersion, relevant for pharmaceutical packaging.

Optical properties

Colorimetry

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

Sample	L*	a*	b*	C*	ΔE*
TP-1.0-0.01CA-PP	46.99	8.39	25.68	27.02	16.90
TP-1.0-0.1CA-PP	49.63	6.21	26.60	27.32	14.0
TP-1.0-PP	42.30	7.05	20.11	21.31	20.7
TP-3.0-PP	31.86	8.10	9.12	12.20	33.7
TP-3.0-0.1CA-PP	27.97	4.36	4.11	5.99	38.9
TP-3.0-0.01CA-PP	31.13	9.47	9.00	13.06	34.7

Table 1. UV–Vis transmittance values (T_{400} and T_{600}) of PP and composites with TP and TP-CA. Transmittance decreases with increasing filler content, indicating enhanced UV-blocking and reduced transparency, with stronger effects observed for TP-CA composites. The ΔE values increase significantly from ~14–21 (1 wt%) to ~33–39 (3 wt%), confirming strong color changes with filler loading. This trend correlates with reduced transmittance in UV–Vis spectra, indicating enhanced UV-blocking and decreased transparency.

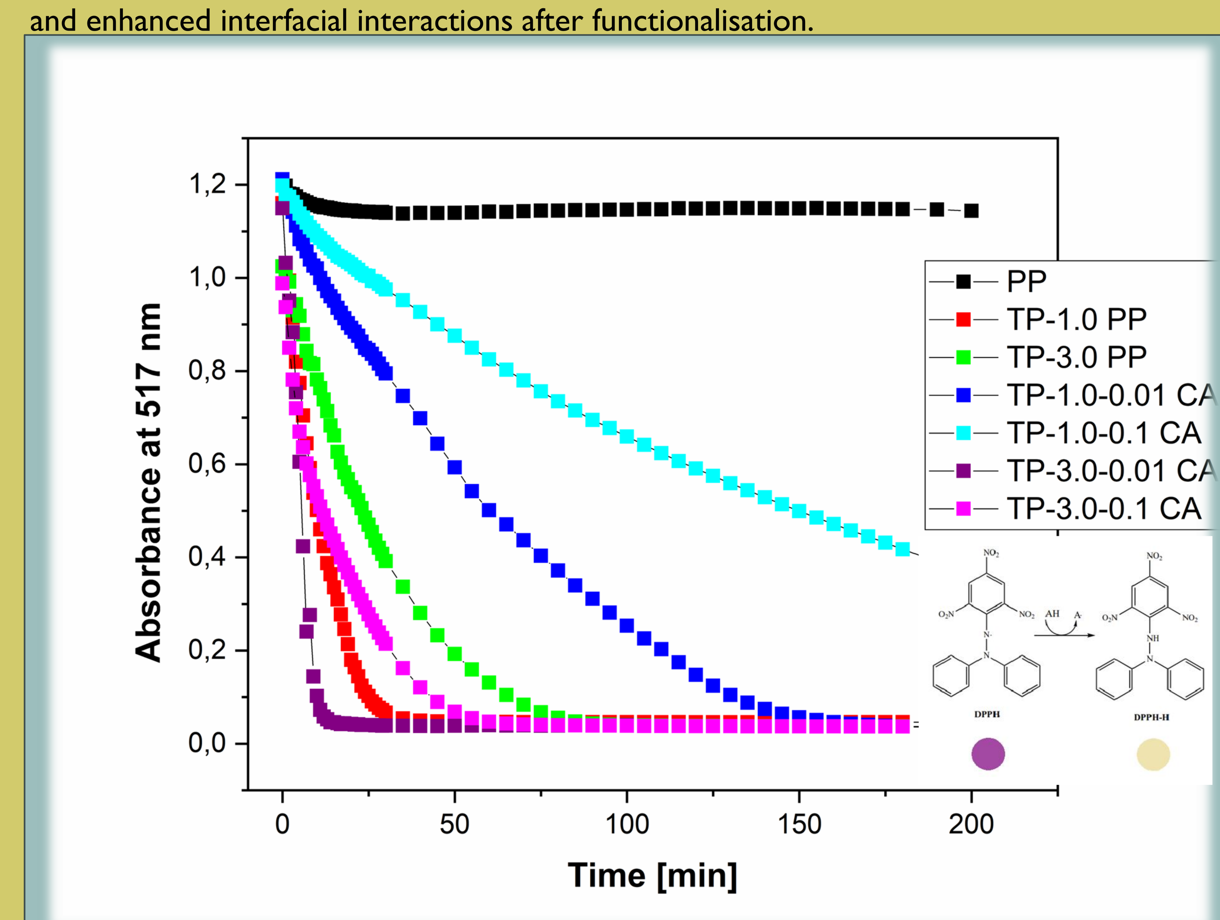


Figure 4. Time-Dependent DPPH Radical Scavenging Behavior of PP Composites with Tannin-Based Functional Additives. The DPPH kinetics reveal that tannin-containing PP composites exhibit rapid and concentration-dependent radical scavenging, with TP-CA showing the fastest and most effective antioxidant activity due to improved dispersion and interfacial interactions.

References

1. Huang, H.-D., Ren, P.-G., Zhong, G.-J., Olah, A., Li, Z.-M., Baer, E., & Zhu, L. (2023). Promising strategies and new opportunities for high barrier polymer packaging films. Progress in Polymer Science, 142, 101768. https://doi.org/10.1016/j.progpolymsci.2023.101768

Acknowledgments

The authors acknowledge Assistant Professor Alenka Ojsteršek for the UV–Vis analysis and the financial support provided by the Slovenian Research Agency (Grant No. P2-0118).