Supramolecular Assembly and Morphological Control of Lignin Colloids via Levulinic Acid Solvents

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The development of functional lignin particles (LPs) represents a fundamental challenge in the valorization of industrial byproducts through the lens of colloid science [1]. In this study, the formation of LPs is controlled via a solvent-shifting process utilizing levulinic acid (LA) and its derivatives—specifically its ethyl ester (EL) and the ketal (K) obtained from EL and glycerol—as sustainable solvent media. The physicochemical driving forces governing the nucleation and growth of these colloids are systematically investigated to establish a correlation between solvent nature and the resulting supramolecular architecture.

It is demonstrated that the choice of solvent fundamentally modulates the internal organization of lignin macromolecules, specifically influencing the degree of π-π stacking between aromatic moieties. This molecular-level control translates into distinct morphological transitions: LA promotes the formation of irregular particle clusters, whereas EL induces the assembly of compact, well-defined spheres, and the ketal derivative leads to the generation of planar fragments. Such structural diversity is linked to the varying solubility parameters and the specific interactions between the lignin backbone and the solvent molecules during the anti-solvent addition.

The characterization of these LPs reveals that the composite structure and high surface area achieved through LA-mediated synthesis result in enhanced functional properties, such as antioxidant capacity. Furthermore, the understanding of these assembly mechanisms is essential for governing the interfacial behaviour of lignin in multiphase systems. These tailored LPs are successfully employed as stabilizers for high-performance Pickering emulsions, platforms for the encapsulation of bioactive compounds, and as reinforcing agents in functional composite hydrogels based on polysaccharides such as alginate and chitosan. This work provides a robust framework for the design of bio-based soft materials with tunable properties for advanced interfacial applications.

Keywords:
Lignin, Levulinic Acid, Antioxidant Properties, Morphology Tuning

References:

[1] Ma, C., Kim, T.-H., Liu, K., Ma, M.-G., Choi, S.-E., Si, C., 2021. Multifunctional lignin-based composite materials for emerging applications. Front. Bioeng. Biotechnol. 9, 708976. https://doi.org/10.3389/fbioe.2021.708976

Acknowledgements:

The authors acknowledge financial support by the Italian MUR, Project Title: Phenolic polymers at biointerfaces (PhenoVectors): selfassembled functional nanovectors with controlled colloidal properties and enhanced antioxidant activity (Project number 202299B4SC) – CUP E53C24002170006 - Grant Assignment Decree No. 18508 adopted on 18/09/2024.