Nanostructured Bio-Based Materials from Agricultural Waste for Enhanced and Functional Performances in Precision Agriculture

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Nanostructured bio-based materials offer significant potential for enhancing material properties in sustainable applications, particularly in precision agriculture. These advanced materials, incorporating nanoparticles (e.g., metal, silica, or carbon-based) and functional cross-linkers (e.g., alkoxysilanes, organic molecules), can be engineered using renewable feedstocks to provide tailored functionalities while maintaining environmental compatibility. A key focus of this study is the valorization of agricultural waste biomasses, particularly cellulose and biochar derivatives, as sustainable precursors for nanostructured materials. By utilizing waste-derived materials, this approach aligns with circular economy principles while offering cost-effective and eco-friendly alternatives for precision farming and other sustainable transversal applications. In the agricultural sector, these materials can be applied to improve soil retention, enhance water management, reduce pesticide dependency, and protect crops from environmental stressors. Additionally, they hold promise for smart agricultural sensors, controlled-release for nutrients, sustainable bio-plastics for food packaging and anti-fouling coatings for irrigation systems. This work integrates nanotechnology with sustainability through the conversion of waste biomasses into high-performance nanostructured materials, employing green synthesis techniques (e.g., sol-gel processing) and reducing reliance on hazardous chemicals. The study explores the rational design and fabrication of bio-based materials, utilizing biochar or cellulose derived products, functional molecules, and blended polymers to achieve targeted properties. Special emphasis is placed on biodegradability, non-toxic formulations, and compatibility with precision farming systems. Finally, the chemical-physical, and morphological properties of the synthesized materials are analyzed, demonstrating their potential to enhance agricultural efficiency while reducing environmental impact. This research contributes to the development of next-generation sustainable materials, leveraging agricultural waste for a more resilient and resource-efficient future in precision agriculture.