

Bio-Nanocomposite Coatings: A Potential Strategy to Improve the Overall Performance of Food Packaging Materials

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Growing concern over the environmental impact of fossil-based plastics used in food packaging has prompted new legislative action (most notably EU Regulation 2025/40, commonly referred to as the “Packaging and Packaging Waste Regulation”) demanding a transition toward more sustainable and highly functional alternatives [1–4]. Within this frame, the usage of natural nanocomposite coatings, either applied in direct contact with food or deposited on the surface of packaging materials, has emerged as a promising strategy aligned with circular economy principles [5–10].

The Special Issue titled “Bio-Nanocomposite Coatings: A Potential Strategy to Improve the Overall Performance of Food Packaging Materials” encompasses six research papers providing recent advances in this field.

Bathi and co-workers [11] assessed the feasibility of using a biocompatible mesoporous silica-based coating to detect latent fingerprints on multiple non-porous surfaces, including glassy and plastic food packaging materials. To this end, silica nanoparticles (Si NPs) with fluorescent properties were synthesized via an oil–water mixed micro-emulsion templating (MET) approach. The morphology, cytotoxicity, stability, and optical properties of the nanoparticles were rigorously examined through SEM, TEM, cell viability, DLS, and UV-Vis absorption tests. The size of NPs did not appreciably vary within 72 h, thus indicating their potential suitability for spray coating applications. Moreover, the mesoporous coatings made it possible to display both the overall pattern and finer features of finger impressions under UV irradiation.

Researchers from Cairo University recently studied the impact of alginate-based zinc oxide nanoparticles (ZnO NPs) coating on the qualitative and microbiological attributes of mango fruits during storage [12]. Remarkably, the developed coating system curtailed the growth of *E. coli* and *S. aureus* bacteria. This behavior was ascribed to the generation of reactive oxygen species (ROS) damaging bacterial proteins, DNA, and lipids, as well as to the inhibition of cellular metabolism and enzyme activity triggered by ZnO NPs. As compared with control (uncoated) samples, coated fruits experienced a slower change in weight loss, respiration rate, firmness, and titratable acidity over 28 days of cold storage. This ultimately ensured better quality, controlled decay incidence, and increased the shelf-life of the tested fruits.

Similar findings were also reported by Alvarez and co-workers, who fabricated pectin–beeswax edible coatings enriched with eugenol, geraniol, propolis extract, or essential oils from winter savory, cinnamon, and myrrh [13]. The effectiveness of these systems to reduce sour rot while preserving the postharvest quality of artificially inoculated oranges was successfully demonstrated through shelf-life tests at 20 °C. The authors concluded

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that the designed coatings represent an efficient multi-target protection strategy against some of the most relevant postharvest pathogenic fungi of citrus fruit, among which *G. citri-aurantii* and *P. digitatum*.

A more recent study explored the use of pectin, glycerol, and ZnO NPs for producing bionanocomposite coatings endowed with antimicrobial properties [14]. These formulations were both cast in Petri dishes to yield self-standing films and applied in their native form to papaya fruits for storage testing. Adding zinc oxide nanoparticles to the coating system negatively impacted the functionality of the ensuing films. Indeed, SEM analyses revealed the presence of nanoparticles aggregates within the main polymer matrix (i.e., pectin) which promoted structural discontinuities, thus compromising mechanical (elastic modulus, elongation at break, and tensile strength) and water-vapor barrier properties. On the other hand, the pectin coating incorporated with the lowest investigated ZnO NPs concentration (0.2 g per 100 g solution) successfully extended papaya shelf-life, as reflected by minimal changes in weight loss, firmness, titratable acidity, and soluble solids over nine days of storage.

In an attempt to overcome the moisture sensitivity and low mechanical properties of gelatin (Gel) coatings for food packaging, Golmohammadi and co-workers employed a “three-step” methodology to incorporate cinnamon essential oils (CEO, 0.03%–0.48% *v/w*) and bacterial cellulose nanocrystals (BCNC, 0.06% *w/w*) into a low-pH aqueous solution of the polymer [15]. The resulting CEO-Gel/BCNC emulsion coatings underwent drying to prepare films, which were further characterized in terms of optical properties (transmittance and haze), wetting behavior (water contact angle), solubility, and tensile performance. CEO was found to increase the film surface repellency toward water whilst reducing the inherent brittleness thereof. Plus, the “see-through capability” of the films did not significantly vary until exceeding 0.24% (*v/w*) of CEO within the film-forming solution. Based on the collected results, the authors suggested the suitability of CEO-Gel/BCNC emulsion systems in the form of edible films/coatings for the preservation of water-sensitive food products, such as fruits, vegetables, meat, and seafood.

Another study delved into the synthesis of starch-based nanocomposite films loaded with cellulose nanocrystals (CNCs) or cellulose nanofibrils (CNFs) at different mass ratios [16]. Interestingly, pure amylose was retrieved from barley grains, whereas both CNCs and CNFs were extracted from sugar beet pulp. FTIR measurements unveiled extensive hydrogen bonding between amylose and cellulose. CNFs produced a more significant improvement in the mechanical and water vapor/oxygen barrier performance of neat amylose films compared with the nanocrystalline counterpart. This was attributed to the denser and more compact structure of CNF-based films which better resisted the applied stress, as well as curbed the penetration of water vapor and oxygen. Irrespective of the employed nanoentity, composite films exhibited a high susceptibility to biodegradation when buried in soil for up to 56 days.

Overall, we are confident that the contributions presented in this Special Issue will stimulate innovative research directions and support ongoing efforts to advance sustainability within the food packaging sector.

Conflicts of Interest: The authors declare no conflict of interest.

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