Materials Research Proceedings 67 (2026) 719-723 https://doi.org/10.21741/9781644904176-99

Morphological properties of Zinc Oxide loaded electrospun Polyethylene furan-2,5-dicarboxylate/ Polyhydroxybutyrate electrospun nanofibers for potential food packaging

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Key words: PEF, PHB, Nanofiber Composites, Zinc Oxide, Electrospinning, Release Kinetics

Abstract. There have been growing safety concerns in society over the utilization of recent technologies, especially in food and medicine. In the food sector, the salient technologies are biotechnology and nanotechnology. Nanotechnology is particularly intriguing because of the puissant properties that are derived from reducing materials to the bottom. One such application is found in food packaging, where nanoparticles have been utilized extensively to counter food contamination and adulterations, along with smart monitoring properties. These nanoscale materials are as great as they present challenges when they excessively leak into the food systems themselves. In this work, we designed electrospun nanofibers loaded with ZnO nanoparticles to elucidate the chemical interaction of the nanoparticles, suitability in applications such as food packaging by establishing the effect of such composites on key parameters that are of paramount focus in the food packaging industry. Our findings indicate improvement of morphological properties of PHB by PEF and branching effect caused by addition of ZnO.Attempts at antibacterial studies didn't yield significant results, but the potential to enhance this property through light-assisted bactericidal action exists.

1. Introduction

Application of nanotechnology in the food sector is a widely researched area with a varied array of dimensions that ultimately converge to ensure high-quality food products over an extended period, status indication, and monitoring.[1], [2], [3] These parameters are what constitute what is widely known as smart packaging. Before the advent of bionano-based food packaging, synthetic plastics were the mainstay of materials. However, given the limitations faced with conventional plastics, such as cost, environmental and health risks, biodegradable and natural polymers have attracted great attention.[4], [5], [6] Biobased polymers such as cellulose, chitosan, Polycyclic hydrocarbons, etc, are abundant in nature and hence provide an easy and sustainable alternative to plastics [7], [8][7], [8]. The main challenge faced with biobased polymers is the weak mechanical strength, high wettability, and low thermal stability [9][9]. Interestingly, when these materials are converted to nanoscale, these properties improve, and when in blend, they augment each other to achieve excellent qualities that suit them for packaging applications.[10], [11], [12] [13] Nano forms of these polymers can be in the form of nanocrystals, nanofibers, thin films, and nanoparticles, each of which presents unique attributes. Nanofibers and nanoparticles are a booming trend in converting polymers into versatile materials for a plethora of applications.

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Furthermore, blended polymers and incorporating nanoparticles increase the performance of these materials by a significant factor. This research work focused on blending poly (ethylene furan dicarboxylate) (PEF) and Polyhydroxy butyrate (PHB), which are biodegradable polymers with immense potential for a wide range of applications. Nanofibers blend from these polymers produce a unique scaffold that can be functionalized to obtain smart packaging properties with active ingredients such as metal oxides.[13] Metal oxides are widely reported for their anti-microbial and antioxidant properties [15][14]. Moreover, metal oxides, when properly incorporated in electrospun nanofibers, impart mechanical strength, conductivity, and barrier performance properties. We chose Zinc oxide (ZnO) an FDA-approved compound with reportedly puissant antibacterial properties. Our results reveal a synergistic effect of these materials on mechanical strength, fiber diameter reduction, and wettability [16][15].

2. Materials and methods

2.1. Materials

Trifluoracetic acid (TFA, 99 %, Pcode:102285924, Lot#STBJ7788), and Zinc Oxide were purchased from signal Aldrich (USA), polyhydroxybutyrate (PHB), and Poly (ethylene furanoate) (PEF) with a molecular weight >30,000 g/mol were purchased from Avantium, Netherlands.

2.2. Characterization of the nanofibers

Electrospun fibers were collected from the electrospinner, dried in a vacuum for 6 hours at 65 °C, before being examined with a scanning electron microscope (SEM) fitted with EDS detector.

3. Results and discussion

PEF polymer proved to be the most easily electrospinnable and the nanofibers obtained exhibited small diameter with narrow fiber diameter distribution (Figure 1a) PHB on the other hand was difficult to spin owing to the presence OH groups on the fiber chains that interfere with the electrostatic repulsion thus slowing the sequestration of the polymer into fibers. Another likely reason for this difficulty is the due to the likely deprotonation of the OH groups by the TFA solvent creating charges on the surface of the polymer that interfere with the electric field and reduce fiber formation. Nanofibers from PHB exhibit larger fiber diameter (Figure 1b) and larger diameter distribution. Blending of the two polymers results in the narrowing of nanofiber diameter (Figure 1c), however, loading ZnO into the blend results in unsurprisingly enormous increase in fiber diameter (Figure 1c). This is generally because of the fluffy nature of the ZnO nanopowder (Figure 1d) that attaches to the surface of the nanofibers thus increasing their sizes. Moreover, the presence of ZnO in the blend is confirmed by the EDX results (Figure 1e). Fibers of small size are generally recommended for efficiency in applications such as antibacterial action due to the increase in the surface area to volume ratio. Interestingly blending of the polymers also improves on the water contact angle of the composite. PEF is generally on the borderline between hydrophobicity and hydrophilicity while PHB exhibited hydrophobic behavior and combining them shifted the blend to the hydrophobic zone (Figure1 inset).

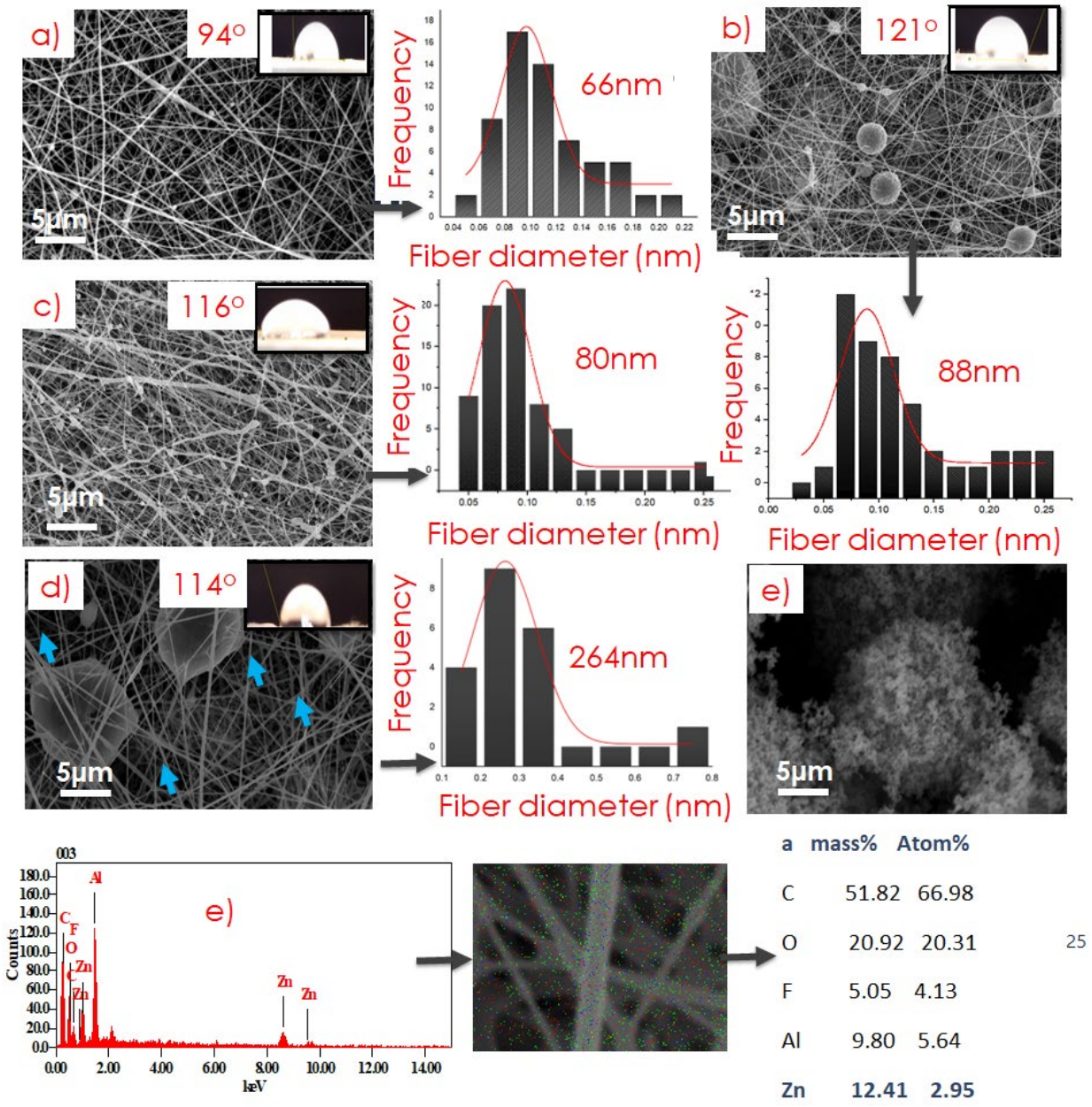


***Figure 1**. SEM micrographs of a) PEF, b) PHB, c) PEF/PHB, d) PEF/PHB+ ZnO, (inset if the water contact angle) and e) EDX analysis of PEF/PHB+ ZnO.*

ZnO loaded electrospun membranes from biodegradable polymers have inherent potential for food packaging with enhanced properties such as antibacterial, and barrier performance against gasses and water. The morphological observations show enormous surface area and branching properties that can entrap microbes and other contaminants thus providing safe and high quality food product.

Conclusion

This project successfully synthesized unique biodegradable nanofibers using electrospinning technique after careful parameter adjustments and results indicate a synergistic effect of blending the two polymers in terms of fiber size and encapsulation of ZnO nanoparticles.. These findings provide a platform for further examination of the resulting membranes in situ on potential food

packaging on different products such diary, fresh vegetables and beef which are highly susceptible to deteroriation.

Acknowledgement
Authors acknowledge and thank the financial support through Abu Dhabi University- United Arab Emirates University (ADU-UAU) joint research grant # 12N139.

References.

[1] K. J. Figueroa-Lopez, C. Prieto, M. Pardo-Figuerez, L. Cabedo, and J. M. Lagaron, "Development and Characterization of Electrospun Poly(3-hydroxybutyrate-co-3-hydroxyvalerate) Biopapers Containing Cerium Oxide Nanoparticles for Active Food Packaging Applications," *Nanomaterials*, vol. 13, no. 5, Mar. 2023. https://doi.org/10.3390/nano13050823.

[2] R. Valizadeh, M. Zandi, A. Ganjloo, and N. Dardmeh, "Bioactive multilayer film based on the sage seed gum-gelatin, TiO2 and electrospun zein fibers encapsulating pomegranate peel extract," *Int J Biol Macromol*, vol. 283, Dec. 2024. https://doi.org/10.1016/j.ijbiomac.2024.137826.

[3] J. L. Castro Mayorga, M. J. Fabra Rovira, L. Cabedo Mas, G. Sánchez Moragas, and J. M. Lagarón Cabello, "Antimicrobial nanocomposites and electrospun coatings based on poly(3-hydroxybutyrate-co-3-hydroxyvalerate) and copper oxide nanoparticles for active packaging and coating applications," *J Appl Polym Sci*, vol. 135, no. 2, Jan. 2018. https://doi.org/10.1002/app.45673.

[4] K. Petersen *et al.*, "Potential of biobased materials for food packaging."

[5] M. Arkoun, F. Daigle, R. A. Holley, M. C. Heuzey, and A. Ajji, "Chitosan-based nanofibers as bioactive meat packaging materials," *Packaging Technology and Science*, vol. 31, no. 4, pp. 185–195, Apr. 2018. https://doi.org/10.1002/pts.2366.

[6] S. Ataei, P. Azari, A. Hassan, B. Pingguan-Murphy, R. Yahya, and F. Muhamad, "Essential Oils-Loaded Electrospun Biopolymers: A Future Perspective for Active Food Packaging," *Advances in Polymer Technology*, vol. 2020, pp. 1–21, Feb. 2020. https://doi.org/10.1155/2020/9040535.

[7] Aslam, R., Sivapragasam, N., Lawal, K. G., Ahmed, Z. F., & Maqsood, S. (2025). Bionanocomposite Films from Camel Skin Gelatin Reinforced with Tannic Acid and Date Seed Nanocellulose. Food Biophysics, 20(3), 119, doi.org/10.1007/s11483-025-10000-z

[8] Kaur, N., Ahmed, Z. F. R., Somasundram, C. Razali, Z., (2024) Sustainable Aloe vera/Chitosan-based Edible Coatings Reduce Postharvest Loss of Stored Fresh Figs (Ficus carica L.). Frontiers in Sustainable Food System 8, 1459600, doi.org/10.3390/polym16020242

[9] Kaur, N.; Somasundram, C.; Razali, Z.; Mourad, A.-H.I.; Hamed, F.; Ahmed, Z.F.R. (2024) Aloe vera/Chitosan-Based Edible Film with Enhanced Antioxidant, Antimicrobial, Thermal, and Barrier Properties for Sustainable Food Preservation. Polymers 16, 242, doi.org/10.3390/polym16020242.

[10] K. E, M. C. K, B. P, T. S. A, and J. C. R. I, "Biocompatible silver nanoparticles/poly(vinyl alcohol) electrospun nanofibers for potential antimicrobial food packaging applications," *Food Packag Shelf Life*, vol. 21, Sep. 2019. https://doi.org/10.1016/j.fpsl.2019.100379, .

[11] S. Amjadi, S. Emaminia, S. Heyat Davudian, S. Pourmohammad, H. Hamishehkar, and L. Roufegarinejad, "Preparation and characterization of gelatin-based nanocomposite containing

chitosan nanofiber and ZnO nanoparticles," *Carbohydr Polym*, vol. 216, pp. 376–384, Jul. 2019. https://doi.org/10.1016/j.carbpol.2019.03.062.

[12] F. Shahmohammadi Jebel and H. Almasi, "Morphological, physical, antimicrobial and release properties of ZnO nanoparticles-loaded bacterial cellulose films," *Carbohydr Polym*, vol. 149, pp. 8–19, Sep. 2016. https://doi.org/10.1016/j.carbpol.2016.04.089.

[13] S. Thongkham, "Environmentally Friendly nanomembrane from PEF-PHBv composites: Preparation and investigation of morphologies, thermal, and mechanical properties," 2023. https://doi.org/10.21203/rs.3.rs-3673950/v1.

[14] Al Yabhouni, L., Subhan, A., Mourad, A. H. I., Francis, D. V., Ahmed, Z. F., & Ramachandran, T. (2025). Antibacterial and photocatalytic activity of chitosan encapsulated Ag/ZnO ternary nanocomposites. Next Research, 100451.

[15] Alhindaassi, H., Almheiri, M. H., Alrayssi, T. A., Francis, D. V., Ali, M., Jaleel, A.,& Ahmed, Z. F. (2025). Ghaf microgreen: a novel functional food with enhanced nutritional content via nanoparticle-seed priming. Future Foods, 100774.".