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Sustainable Electrospinning of Cellulose and Lignin Nanofibers: A Green Approach for Food Packaging Innovation

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Introduction With the increasing global concern over environmental sustainability and the need for eco-friendly alternatives, there has been growing interest in developing innovative materials for food packaging applications. Bacterial nanocellulose (BCN), microfibril cellulose (MFC), and lignin, derived from renewable resources and a byproduct of the pulp and paper industry, respectively, have gained attention for their remarkable properties. These nanofibers exhibit desirable mechanical properties and thermal resistance, making them suitable for barrier coatings in active and intelligent food packaging products. However, their low solubility and limited processability have posed challenges. Recent research has found that ionic liquids (ILs) and deep eutectic solvents (DESs) show promise as sustainable alternatives for processing lignocellulose-based materials, offering advantages such as high dissolving ability and environmental friendliness [1]. This study focuses on a comprehensive survey of producing bacterial cellulose and lignin nanofibers via electrospinning, emphasizing green solvents like ILs and DESs. It explores their potential applications in sustainable food packaging.

Experimental BCN synthesized at Sheffield University, MFC delignificated at University of Tehran and Lignin Kraft fractionated at University of Venice were used. Lignin alkali and all applied solvents were purchased from Sigma Aldrich. The solution properties and electrospinning conditions used in the study are shown in Table 1.

Table 1. Solution properties and electrospinning conditions for different solutions

Polymer	**Solvents**	**concentration (w%)**	**Voltage (kV)**	**distance (cm)**	**Flow Rate (ml/hr)**
BCN	DMSO: [Bmim]OAc (3:1 w/w)	3 wt%	19-22	9	0.5
MFC	DMSO: [Bmim]OAc (3:1 w/w)	3-5 wt%	19-22	9	0.5
BCN	γ-Valerolactone: [Bmim]OAc (3:1 w/w)	3 wt%	19	12	0.5
BCN	Choline Chloride: Oxalic Acid (1:1)	6 wt%	25	8	0.05
Lignin/PVA (98/2 w/w%)	Choline Chloride: Lactic Acid (1:2)	20 wt%	21	10	0.03

Results and Discussion

In this study, a solvent mixture of DMSO and [Bmim]OAc (3:1 w/w) demonstrated successful dissolution of BCN up to 3 wt% and MFC up to 5 wt%. γ-Valerolactone was found to be a viable alternative to DMSO, effectively dissolving BC and yielding a solution suitable for electrospinning with good spinnability. The combination of Choline Chloride and Oxalic Acid (1:1) solvent successfully dissolved BC, while Choline Chloride and Lactic Acid (1:2) effectively dissolved lignin when combined with PVA (98/2 w/w%). The solubility characteristics corresponded with the viscosity trend observed in the BCN and MFC solution, indicating an optimal viscosity range for electrospinning and fiber formation (Figure 1). BCN from DMSO: [Bmim]OAc and γ-Valerolactone: [Bmim]OAc (1:3 w/w) had an average diameter of 0.52 ±0.35 μm and 0.57 ± 0.33 μm respectrively. Using Choline Chloride: Oxalic Acid (1:1) as solvent resulted in BCN fibers with a diameter of 1.89 ± 2.53 μm, and lignin fibers with an average diameter of 10.89 ± 4.05 μm were obtained using Choline Chloride: Lactic Acid (1:2) as solvent.

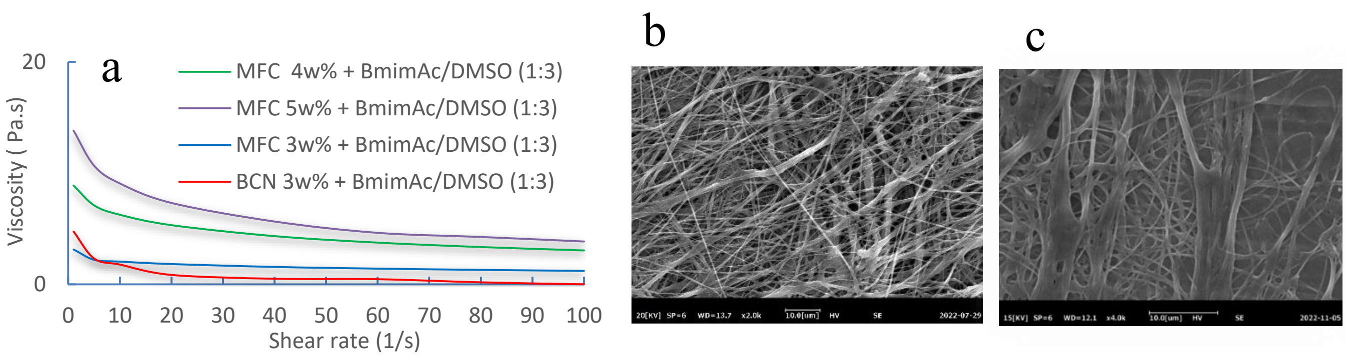

Figure 1. a) Viscosity behavior of BCN and MFC in DMSO: [Bmim]OAc (3:1 w/w), and b,c) SEM image of electrospun BCN nanofiber using DMSO: [Bmim]OAc (1:3 w/w) and γ-Valerolactone: [Bmim]OAc (1:3 w/w) as solvents respectively.

Conclusions

In conclusion, the production of bacterial cellulose and lignin nanofibers by electrospinning using green solvents holds significant promise for food packaging applications. The use of sustainable materials, such as cellulose and lignin, offers the advantage of low cost while maintaining desirable mechanical and barrier properties. By leveraging the electrospinning technique and optimizing solvent selection, continuous and uniform nanofibers can be produced, paving the way for the development of environmentally friendly and high-performance food packaging materials.

Biography: Elona Vasili is a 2nd year PhD student at the Department of Civil and Industrial Engineering of the University of Pisa. Her research is co-financing by the European Union – FSE REACT-EU, PON Research, and Innovation 2014-2020 - DM 1062/2021, and it is focused on the development of electrospinning processes of nanocellulose from lignocellulosic biomass and bacterial fermentation.

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