




Editorial

# Current Progress in Biopolymer-Based Bionanocomposites and Hybrid Materials

R. A. Ilyas <sup>1,2,3,\*</sup> , S. M. Sapuan <sup>4</sup>  and Emin Bayraktar <sup>5</sup> 

<sup>1</sup> School of Chemical and Energy Engineering, Faculty of Engineering, Universiti Teknologi Malaysia (UTM), Johor Bahru 81310, Malaysia

<sup>2</sup> Centre for Advanced Composite Materials, Universiti Teknologi Malaysia (UTM), Johor Bahru 81310, Malaysia

<sup>3</sup> Institute of Tropical Forest and Forest Products (INTROP), Universiti Putra Malaysia, Serdang 43400, Malaysia

<sup>4</sup> Advanced Engineering Materials and Composites, Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, Universiti Putra Malaysia, Serdang 43400, Malaysia

<sup>5</sup> School of Mechanical and Manufacturing Engineering, ISAE-SUPMECA Institute of Mechanics of Paris, 93400 Saint-Ouen, France

\* Correspondence: ahmadilyas@utm.my

*Current Progress in Biopolymer-Based Bionanocomposites and Hybrid Materials* is a newly opened Special Issue of *Polymers*, which aims to publish original and review papers on the new scientific and applied research and make boundless contributions to the findings and understanding of the reinforcing effects of various synthetic and natural fibres on the performance of biopolymer composites. This Special Issue also covers the hybrid nanofibre-reinforced biopolymer nanocomposites' fundamentals, characterisation, and applications.

In recent years, the development of biopolymers based on constituents obtained from natural resources has been gaining much attention [1,2]. The exploitation of biopolymers to engineer advanced bionanocomposites and hybrid materials is the focus of increasing scientific activity, explained by the growing environmental concerns and the interest in the novel features and multiple functionalities of these macromolecules.

Today, nanomaterial-reinforced polymers are used in several applications including in packaging [2–4]; electronic, electrical, structural, and energy storage [5]; in automotives [6]; in filter, coating, and bone tissue engineering, and in drug delivery [7], and more. The continuous development and appearance on the market of new high-performance reinforcing nanomaterials in polymer composites have constituted a strong challenge for researchers to design and adapt new functional nano-composites for several applications. The term bionanocomposites was introduced several years ago to express an emerging class of bionano- and bionano-hybrid materials, resulting from the reinforcement of biopolymers, such as proteins (gelatin, casein, soy, and gluten), polysaccharides (cellulose, starch, chitosan, pectin, alginate, carrageenan, and glycogen), lipids (cutin), and nucleic acids with inorganic or organic solids at the nanoscale [8–13]. Such organic fractions comprise nanocrystalline cellulose [14–16], nanofibrillated cellulose [17,18] (Figure 1), bacterial nanocellulose [19], and lignin nanoparticles [20], whereas inorganic fractions consist of finely divided solids, spanning from clays to phosphates or carbonates, whose origins can be either synthetic or natural.

As will become increasingly clear for the reader throughout the collection of authoritative research and reviews in this Special Issue, the relevance of coupling biopolymers with organic and inorganic fillers, through innovative architectures, is twofold. First, it contradicts the idea that biopolymers are either eco-friendly or high-performance. Second, it demonstrates how the properties resulting from these biopolymers are highly significant in applications such as food packaging, water treatment, gas-diffusion barriers, electronic devices, agriculture, sensing devices, flame retardancy, automotive parts, adhesives, regenerative medicine, tissue engineering, and drug delivery [21].



**Citation:** Ilyas, R.A.; Sapuan, S.M.; Bayraktar, E. Current Progress in Biopolymer-Based Bionanocomposites and Hybrid Materials. *Polymers* **2022**, *14*, 3479. <https://doi.org/10.3390/polym14173479>

Received: 19 August 2022

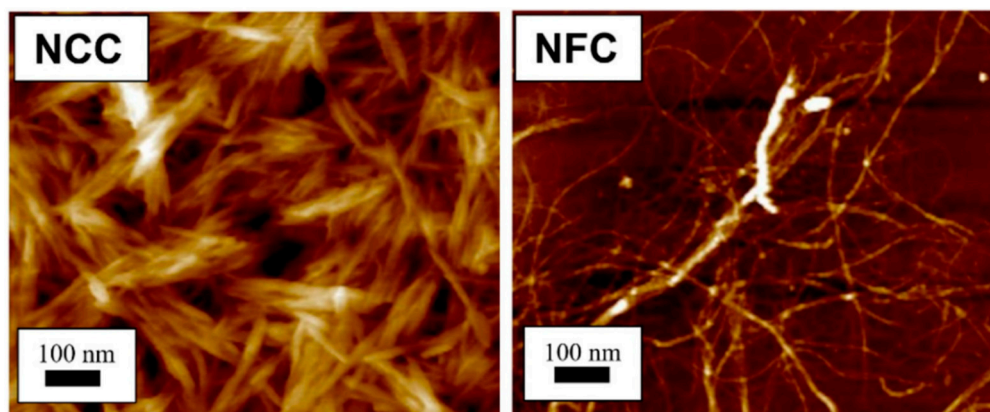
Accepted: 19 August 2022

Published: 25 August 2022

**Publisher's Note:** MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



**Copyright:** © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).



**Figure 1.** Atomic force microscopy images show different structures between nanocrystalline cellulose (NCC) and nanofibrillated cellulose (NFC).

In this Special Issue, we aim to capture the cutting edge of the state of the art in research pertaining to biopolymer-based bionanocomposites and hybrid materials and their advanced applications. Contributions to the processing of biopolymers and bionanocomposites, the use of diverse biopolymer sources such as polysaccharides, the reinforcement of nanosized materials with biopolymers, and applications of these biopolymers, bionanocomposites, and biohybrid materials will constitute the backbone of this Special Issue.

**Author Contributions:** Conceptualization, R.A.I., S.M.S. and E.B.; writing—original draft preparation, R.A.I., S.M.S. and E.B.; writing—review and editing, R.A.I., S.M.S. and E.B.; project administration, R.A.I., S.M.S. and E.B. All authors have read and agreed to the published version of the manuscript.

**Funding:** The authors would like express gratitude for the financial support received from the Universiti Teknologi Malaysia for the project “The impact of Malaysian bamboos’ chemical and fibre characteristics on their pulp and paper properties”, grant number PY/2022/02318—Q.J130000.3851.21H99. The research has been carried out under the programme, Research Excellence Consortium (JPT (BPKI) 1000/016/018/25 (57)), provided by the Ministry of Higher Education Malaysia (MOHE).

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

## References

1. Tarique, J.; Sapuan, S.M.; Khalina, A.; Ilyas, R.A.; Zainudin, E.S. Thermal, flammability, and antimicrobial properties of arrowroot (*Maranta arundinacea*) fiber reinforced arrowroot starch biopolymer composites for food packaging applications. *Int. J. Biol. Macromol.* **2022**, *213*, 1–10. [[CrossRef](#)] [[PubMed](#)]
2. Nazrin, A.; Sapuan, S.M.; Zuhri, M.Y.M.; Tawakkal, I.S.M.A.; Ilyas, R.A. Flammability and physical stability of sugar palm crystalline nanocellulose reinforced thermoplastic sugar palm starch/poly (lactic acid) blend bionanocomposites. *Nanotechnol. Rev.* **2022**, *11*, 86–95. [[CrossRef](#)]
3. Rozilah, A.; Jaafar, C.N.A.; Sapuan, S.M.; Zainol, I.; Ilyas, R.A. The Effects of Silver Nanoparticles Compositions on the Mechanical, Physiochemical, Antibacterial, and Morphology Properties of Sugar Palm Starch Biocomposites for Antibacterial Coating. *Polymers* **2020**, *12*, 2605. [[CrossRef](#)] [[PubMed](#)]
4. Alias, A.H.; Norizan, M.N.; Sabaruddin, F.A.; Asyraf, M.R.M.; Norrrahim, M.N.F.; Ilyas, A.R.; Kuzmin, A.M.; Rayung, M.; Shazleen, S.S.; Nazrin, A.; et al. Hybridization of MMT/Lignocellulosic Fiber Reinforced Polymer Nanocomposites for Structural Applications: A Review. *Coatings* **2021**, *11*, 1355. [[CrossRef](#)]
5. Nurazzi, N.M.; Sabaruddin, F.A.; Harussani, M.M.; Kamarudin, S.H.; Rayung, M.; Asyraf, M.R.M.; Aisyah, H.A.; Norrrahim, M.N.F.; Ilyas, R.A.; Abdullah, N.; et al. Mechanical Performance and Applications of CNTs Reinforced Polymer Composites—A Review. *Nanomaterials* **2021**, *11*, 2186. [[CrossRef](#)]
6. Nurazzi, N.M.; Asyraf, M.R.M.; Rayung, M.; Norrrahim, M.N.F.; Shazleen, S.S.; Rani, M.S.A.; Shafi, A.R.; Aisyah, H.A.; Radzi, M.H.M.; Sabaruddin, F.A.; et al. Thermogravimetric Analysis Properties of Cellulosic Natural Fiber Polymer Composites: A Review on Influence of Chemical Treatments. *Polymers* **2021**, *13*, 2710. [[CrossRef](#)]
7. Sharma, S.; Sudhakara, P.; Singh, J.; Ilyas, R.A.; Asyraf, M.R.M.; Razman, M.R. Critical Review of Biodegradable and Bioactive Polymer Composites for Bone Tissue Engineering and Drug Delivery Applications. *Polymers* **2021**, *13*, 2623. [[CrossRef](#)]

8. Ilyas, R.A.; Zuhri, M.Y.M.; Aisyah, H.A.; Asyraf, M.R.M.; Hassan, S.A.; Zainudin, E.S.; Sapuan, S.M.; Sharma, S.; Bangar, S.P.; Jumaidin, R.; et al. Natural Fiber-Reinforced Polylactic Acid, Polylactic Acid Blends and Their Composites for Advanced Applications. *Polymers* **2022**, *14*, 202. [[CrossRef](#)]
9. Norfarhana, A.S.; Ilyas, R.A.; Ngadi, N. A review of nanocellulose adsorptive membrane as multifunctional wastewater treatment. *Carbohydr. Polym.* **2022**, *291*, 119563. [[CrossRef](#)]
10. Ilyas, R.A.; Zuhri, M.Y.M.; Norrrahim, M.N.F.; Misenan, M.S.M.; Jenol, M.A.; Samsudin, S.A.; Nurazzi, N.M.; Asyraf, M.R.M.; Supian, A.B.M.; Bangar, S.P.; et al. Natural Fiber-Reinforced Polycaprolactone Green and Hybrid Biocomposites for Various Advanced Applications. *Polymers* **2022**, *14*, 182. [[CrossRef](#)]
11. Ilyas, R.A.; Aisyah, H.A.; Nordin, A.H.; Ngadi, N.; Zuhri, M.Y.M.; Asyraf, M.R.M.; Sapuan, S.M.; Zainudin, E.S.; Sharma, S.; Abral, H.; et al. Natural-Fiber-Reinforced Chitosan, Chitosan Blends and Their Nanocomposites for Various Advanced Applications. *Polymers* **2022**, *14*, 874. [[CrossRef](#)] [[PubMed](#)]
12. Nabilah Haris, N.I.; Hassan, M.Z.; Ilyas, R.A.; Suhot, M.A.; Sapuan, S.M.; Dolah, R.; Mohammad, R.; Asyraf, M.R.M. Dynamic mechanical properties of natural fiber reinforced hybrid polymer composites: A review. *J. Mater. Res. Technol.* **2022**, *19*, 167–182. [[CrossRef](#)]
13. Ilyas, R.A.; Sapuan, S.M.; Asyraf, M.R.M.; Dayana, D.A.Z.N.; Amelia, J.J.N.; Rani, M.S.A.; Norrrahim, M.N.F.; Nurazzi, N.M.; Aisyah, H.A.; Sharma, S.; et al. Polymer Composites Filled with Metal Derivatives: A Review of Flame Retardants. *Polymers* **2021**, *13*, 1701. [[CrossRef](#)] [[PubMed](#)]
14. Ilyas, R.A.; Sapuan, S.M.; Atikah, M.S.N.; Asyraf, M.R.M.; Rafiqah, S.A.; Aisyah, H.A.; Nurazzi, N.M.; Norrrahim, M.N.F. Effect of hydrolysis time on the morphological, physical, chemical, and thermal behavior of sugar palm nanocrystalline cellulose (*Arenga pinnata* (Wurmb.) Merr). *Text. Res. J.* **2021**, *91*, 152–167. [[CrossRef](#)]
15. Abral, H.; Ariksa, J.; Mahardika, M.; Handayani, D.; Aminah, I.; Sandrawati, N.; Pratama, A.B.; Fajri, N.; Sapuan, S.M.; Ilyas, R.A. Transparent and antimicrobial cellulose film from ginger nanofiber. *Food Hydrocoll.* **2020**, *98*, 105266. [[CrossRef](#)]
16. Sabaruddin, F.A.; Paridah, M.T.; Sapuan, S.M.; Ilyas, R.A.; Lee, S.H.; Abdan, K.; Mazlan, N.; Roseley, A.S.M.; Abdul Khalil, H.P.S. The effects of unbleached and bleached nanocellulose on the thermal and flammability of polypropylene-reinforced kenaf core hybrid polymer bionanocomposites. *Polymers* **2020**, *13*, 116. [[CrossRef](#)]
17. Ilyas, R.A.; Sapuan, S.M.; Ishak, M.R.; Zainudin, E.S. Sugar palm nanofibrillated cellulose (*Arenga pinnata* (Wurmb.) Merr): Effect of cycles on their yield, physic-chemical, morphological and thermal behavior. *Int. J. Biol. Macromol.* **2019**, *123*, 379–388. [[CrossRef](#)] [[PubMed](#)]
18. Syafri, E.; Sari, N.H.; Mahardika, M.; Amanda, P.; Ilyas, R.A. Isolation and characterization of cellulose nanofibers from *Agave gigantea* by chemical-mechanical treatment. *Int. J. Biol. Macromol.* **2022**, *200*, 25–33. [[CrossRef](#)]
19. Abral, H.; Chairani, M.K.; Rizki, M.D.; Mahardika, M.; Handayani, D.; Sugiarti, E.; Muslimin, A.N.; Sapuan, S.M.; Ilyas, R.A. Characterization of compressed bacterial cellulose nanopaper film after exposure to dry and humid conditions. *J. Mater. Res. Technol.* **2021**, *11*, 896–904. [[CrossRef](#)]
20. Trevisan, H.; Rezende, C.A. Pure, stable and highly antioxidant lignin nanoparticles from elephant grass. *Ind. Crops Prod.* **2020**, *145*, 112105. [[CrossRef](#)]
21. Mohd Nurazzi, N.; Asyraf, M.R.M.; Khalina, A.; Abdullah, N.; Sabaruddin, F.A.; Kamarudin, S.H.; Ahmad, S.; Mahat, A.M.; Lee, C.L.; Aisyah, H.A.; et al. Fabrication, Functionalization, and Application of Carbon Nanotube-Reinforced Polymer Composite: An Overview. *Polymers* **2021**, *13*, 1047. [[CrossRef](#)] [[PubMed](#)]

## Short Biography of Authors



**R. A. Ilyas** is a senior lecturer at the School of Chemical and Energy Engineering, in the Faculty of Engineering, at the Universiti Teknologi Malaysia (UTM), Malaysia. He received his Diploma in Forestry at Universiti Putra Malaysia, Bintulu Campus (UPMKB), Sarawak, Malaysia, from May 2009 to April 2012. In 2012, he was awarded the Public Service Department (JPA) scholarship to pursue his bachelor's degree (BSc) in Chemical Engineering at Universiti Putra Malaysia (UPM). Upon completing his BSc programme in 2016, he was awarded the Graduate Research Fellowship (GRF) by the Universiti Putra Malaysia (UPM) to undertake a PhD degree in the field of Biocomposite Technology and Design at Institute of Tropical Forestry and Forest Products (INTROP) UPM. R.A. Ilyas was the recipient of the MVP Doctor of Philosophy Gold Medal Award UPM 2019, for the Best Ph.D. Thesis and Top Student Award, INTROP, UPM. He was awarded Outstanding Reviewer by Carbohydrate Polymers, Elsevier United Kingdom; Best Paper Award (11th AUN/SEED-Net Regional Conference on Energy Engineering); National Book Award 2018, Best Paper Award (Seminar Enau Kebangsaan 2019, Persatuan Pembangunan dan Industri Enau Malaysia); Top Cited Article 2020-2021, Journal Polymer Composite, Wiley, 2022. R.A. Ilyas was also listed among the World's Top 2% Scientists (Subject-Wise) citation impact during the single calendar year between 2019 and 2020 by Stanford University, US, and awarded the PERINTIS Publication Award 2021 and 2022 by Persatuan Saintis Muslim Malaysia, the Emerging Scholar Award by Automotive and Autonomous Systems 2021, Belgium, Young Scientists Network—Academy of Sciences Malaysia (YSN-ASM) 2021, the UTM Young Research Award 2022, UTM Publication Award 2022, and the UTM Highly Cited Researcher Award 2022. His main research interests are: (1) polymer engineering (biodegradable polymers, biopolymers, polymer composites, and polymer gels) and (2) material engineering (natural fibre-reinforced polymer composites, biocomposites, cellulose materials, and nano-composites). To date, he has authored or co-authored more than 404 publications (published/accepted): 164 Journals Indexed in JCR/Scopus, 2 non-index Journal, 15 books, 104 book chapters, 78 conference proceedings/seminars, 4 research bulletins, 10 conference papers (abstract published in book of abstract), 17 Guest Editor of Journal Special Issues and 10 Editor/Co-Editor of Conference/Seminar Proceedings on green materials related subjects.



**S.M. Sapuan** is an "A" Grade Professor of composite materials at the Department of Mechanical and Manufacturing, Universiti Putra Malaysia (UPM) and a Head of Laboratory of Biocomposite Technology, INTROP, UPM. He has a BEng in Mechanical Engineering from the University of Newcastle, Australia, an MSc in Engineering Design from Loughborough University, UK, and a PhD in Material Engineering from De Montfort University, UK. He is a Professional Engineer, a Society of Automotive Engineers Fellow, an Academy of Science Malaysia Fellow, a Plastic and Rubber and Institute Malaysia Fellow, a Malaysian Scientific Association Fellow, an International Biographical Association Fellow, and an Institute of Material Malaysia Fellow. He is an Honorary Member and immediate past Vice President of the Asian Polymer Association based in IIT Delhi and the Founding Chairman and Honorary Member of Society of Sugar Palm Development and Industry, Malaysia. He is the co-editor-in-chief of Functional Composites and Structures, and a member of editorial boards of more than two dozen journals. To date he has produced more than 1800 publications including over 860 journal papers, 50 books, and 175 chapters in book. He has delivered over 50 plenary and keynote lectures, and over 150 invited lectures. He organized 30 journal special issues as a guest editor, presented over 650 technical articles in conferences and seminars, reviewed over 1300 journal papers, and has eight patents. He successfully supervised 91 PhD and 70 MSc students and 15 postdoctoral researchers. His current h-index is 93 and the number of citations is 31,647 (Google Scholar). He received nine Outstanding Researcher Awards from UPM, ISESCO Science Award (Gold Medal), Plastic and Rubber Institute Malaysia Fellowship Award and Forest Research Institute Malaysia First Prize Publication Award. He also received the Khwarizimi International Award, the SEARCA Regional Professorial Chair award, the Kuala Lumpur Royal Rotary Gold Medal Research Award, and two National Book Awards. He received the Endeavour Research Promotion Award by TMU/IEEE India; the Citation of Excellence Award, Emerald, UK; Malaysia's Research Star Award, Elsevier/Ministry of

Education Malaysia; the Publons Peer Review Award, Publons, USA; the Professor of Eminence Award from Aligarh Muslim University, India; the Top Research Scientists' Malaysia Award, Academy of Science Malaysia; the Gold in Invention and Innovation Awards; the Malaysia Technology Expo; PERINTIS Publication Award, PERINTIS, Malaysia. He was listed among the World Top 2% Scientists by Stanford University, USA. He is the finalist of IET Achievements Award, IET, UK and the 2021 SAE Subir Chowdhury Medal of Quality Leadership, SAE, USA.



**Emin Bayraktar** (Prof. Emeritus, Habil., Dr (Ph.D.), DSc—Doctor of Science) is an academic and research staff member in Mechanical and Manufacturing engineering at SUPMECA/Paris, France. His research areas include manufacturing techniques of new materials (basic composites—hybrid), the metal forming of thin sheets (design + test + FEM), static and dynamic behavior and optimization of materials (experimental and FEM—utilization and design of composite-based metallic and non-metallic, powder metallurgy, and energetic material aeronautical applications), metallic-based and non-metallic materials, powder metallurgy and metallurgy of steels, welding, and heat treatment, as well as the processing of new composites, sintering techniques, sinter-forging, thixoforming, etc. He has authored more than 200 publications in the International Journals and International Conference Proceedings and has also authored more than 90 research reports (European = Steel Committee projects, Test + Simulation). He already advised 32 Ph.D. and 120 MSc theses and is currently advising seven. He is a Fellow of WAMME (World Academy of Science in Materials and Manufacturing Engineering), an Editorial Board—Member of JAMME (*International Journal of Achievement in Materials and Manufacturing Engineering*), an Advisory board member of AMPT—2009 (*Advanced Materials Processing technologies*), and a member of APCMP—2008 and APCMP—2010. He was a Visiting Professor at Nanyang Technology University, Singapore in 2012; Xi'an Northwestern Technical University, Aeronautical Engineering, in 2016; University of Campinas, UNICAMP-Brazil in 2013 until 2023. He is a recipient of the Silesian University Prix pour "FREDERIK STAUB Golden Medal-2009" by the Academy of WAMME, "World Academy of Science"—Poland, materials science section, and a recipient of the William Johnson International Gold Medal—2014, AMPT academic association.