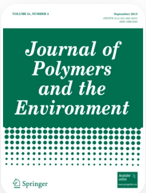
Recent Approaches on the Application of Agro Waste Derived Biocomposites as Green Support Matrix for Enzyme Immobilization

Review Published: 14 September 2022

Volume 30, pages 4936–4960, (2022) Cite this article



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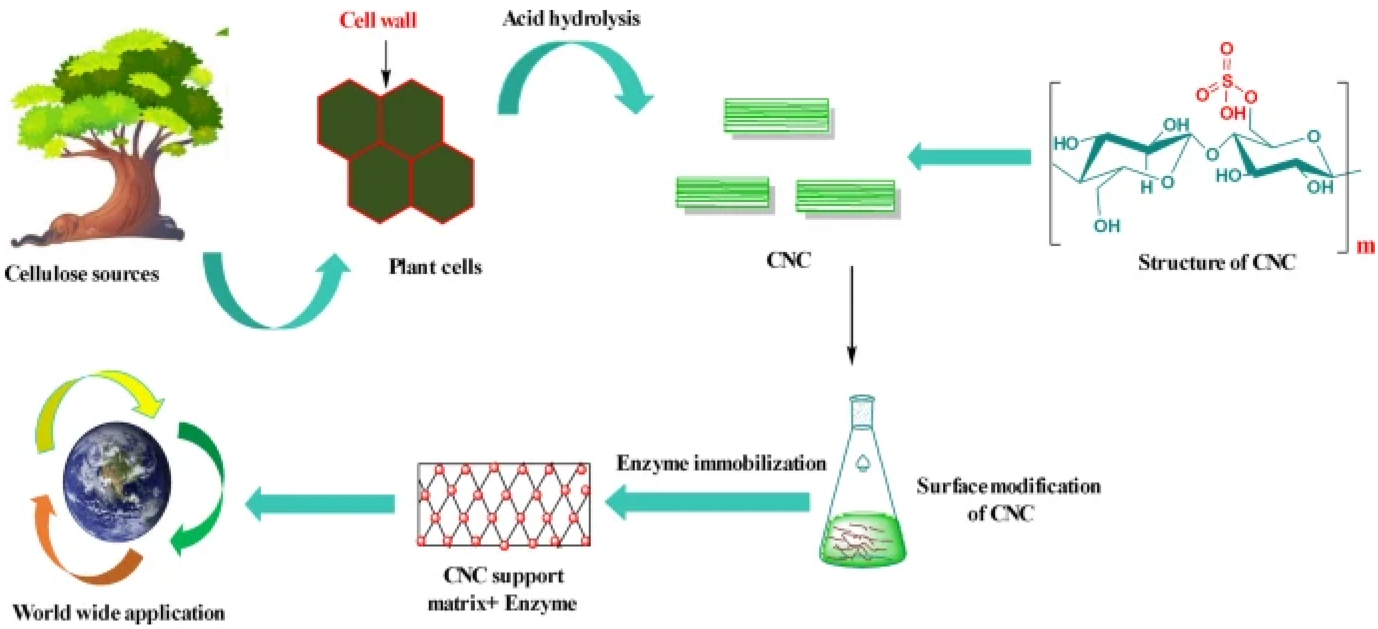
Harshdeep Rana, Amita Sharma, Subhasish Dutta & Saswata Goswami

Abstract

The present imperative interest is in recycling lignocellulosic wastes arising from the global activities of agriculture and forest-based industries. Lignocellulosic waste valorization may help to produce natural biopolymer-based products and their applications in biomedical, biopharmaceutical, and industrial fields. Among these, crystalline nanocellulose (CNC), a cellulose nano-derivative having better enzymatic performance, production yield through immobilization contributes to a green technology and sustainable sources. This is a comprehensive review on the development of cellulose based support matrices, where surface modification of nanocellulose, nanocellulose-protein interactions and applications of cellulose based composites have been illustrated.

Hence, this novel step to recycle primary and secondary agricultural solid waste management will develop pollution free environment, double farmer's income, and cheaper biomaterial for enzyme immobilization that will minimize the process cost value.

Graphical abstract



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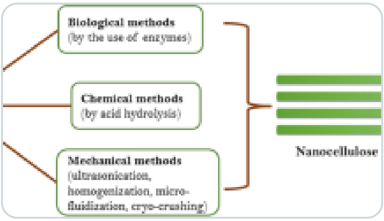

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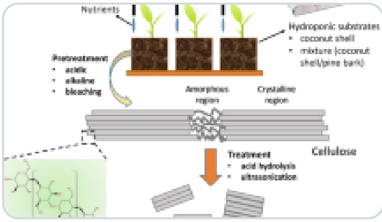

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References

1. APEDA (2014) Agricultural and processed food products export development authority. India New Delhi,

2. Department SR (2020) Production volume of pulp and fruit juice across India from FY 2015 to FY 2020 (in 1000 metric tons). India New Delhi. Accessed 04/09/2020 2020

3. Technology I-CIoP-HE (2020). https://www.ciphet.in/. Accessed 04.07.2020 2020

4. Gowman AC, Picard MC, Lim L, Misra M, Mohanty AK (2019) Fruit waste valorization for biodegradable biocomposite applications: a review. BioResources 14(4):10047–10092

Article Google Scholar

5. Arsalan A, Younus H (2018) Enzymes and nanoparticles: modulation of enzymatic activity via nanoparticles. Int J Biol Macromol 118:1833–1847

Article PubMed CAS Google Scholar

6. Nguyen HH, Kim M (2017) An overview of techniques in enzyme immobilization. Appl Sci Converg Technol 26(6):157–163

Article Google Scholar

7. Mohamad NR, Marzuki NHC, Buang NA, Huyop F, Wahab RA (2015) An overview of technologies for immobilization of enzymes and surface analysis techniques for immobilized enzymes. Biotechnol Biotechnol Equip 29(2):205–220

Article PubMed PubMed Central CAS Google Scholar

8. Zhang B, Weng Y, Xu H, Mao Z (2012) Enzyme immobilization for biodiesel production. Appl Microbial Biotechnol 93(1):61–70

Article Google Scholar

9. Sirisha VL, Jain A, Jain A (2016) Enzyme immobilization: an overview on methods, support material, and applications of immobilized enzymes. Adv in Food and Nutr Res 79:179–211

Article CAS Google Scholar

10. Zhang H, Lyu S, Zhou X, Gu H, Ma C, Wang C, Ding T, Shao Q, Liu H, Guo Z (2019) Super light 3D hierarchical nanocellulose aerogel foam with superior oil adsorption. J Colloid Interface Sci 536:245–251

Article PubMed CAS Google Scholar

11. Ahmed IN, Yang X-L, Dubale AA, Li R-F, Ma Y-M, Wang L-M, Hou G-H, Guan R-F, Xie M-H (2018) Hydrolysis of cellulose using cellulase physically immobilized on highly stable zirconium based metal-organic frameworks. Bioresour Technol 270:377–382

Article PubMed CAS Google Scholar

12. Ali M, Husain Q, Sultana S, Ahmad M (2018) Immobilization of peroxidase on polypyrrole-cellulose-graphene oxide nanocomposite via non-covalent interactions for the degradation of Reactive Blue 4 dye. Chemosphere 202:198–207

Article PubMed CAS Google Scholar

13. Yakout AA, El-Sokkary RH, Shreadah MA, Hamid OGA (2017) Cross-linked graphene oxide sheets via modified extracted cellulose with high metal adsorption. Carbohydr Polym 172:20–27

Article PubMed CAS Google Scholar

14. Xu C, Molino BZ, Wang X, Cheng F, Xu W, Molino P, Bacher M, Su D, Rosenau T, Willför S (2018) 3D printing of nanocellulose hydrogel scaffolds with tunable mechanical strength towards wound healing application. J Mater Chem B 6(43):7066–7075

Article PubMed CAS Google Scholar

15. Zhao X, Qi F, Yuan C, Du W, Liu D (2015) Lipase-catalyzed process for biodiesel production: enzyme immobilization, process simulation and optimization. Renew Sust Energ Rev 44:182–197

Article CAS Google Scholar

16. Ghodake GS, Yang J, Shinde SS, Mistry BM, Kim D-Y, Sung J-S, Kadam AA (2018) Paper waste extracted α-cellulose fibers super-magnetized and chitosan-functionalized for covalent laccase immobilization. Bioresour Technol 261:420–427

Article PubMed CAS Google Scholar

17. Soltani Firooz N, Panahi R, Mokhtarani B, Yazdani F (2017) Direct introduction of amine groups into cellulosic paper for covalent immobilization of tyrosinase: support characterization and enzyme properties. Cellulose 24:1407–1416

Article CAS Google Scholar

18. Vasconcelos NF, Andrade FK, Vieira LdAP, Vieira RS, Vaz JM, Chevallier P, Mantovani D, de Fátima BM, de Freitas RM (2020) Oxidized bacterial cellulose membrane as support for enzyme immobilization: properties and morphological features. Cellulose 27(6):3055–3083

Article CAS Google Scholar

19. Wang L, Zhi W, Wan J, Han J, Li C, Wang Y (2019) Recyclable β-glucosidase by one-pot encapsulation with Cu-MOFs for enhanced hydrolysis of cellulose to glucose. ACS Sustain Chem Eng 7(3):3339–3348

Article CAS Google Scholar

20. Patel SR, Yap MGS, Wang DIC (2009) Immobilization of l-lactate dehydrogenase on magnetic nanoclusters for chiral synthesis of pharmaceutical compounds. Biochem Eng J 48(1):13–21

Article Google Scholar

21. Prakasham RS, Devi GS, Rao CS, Sivakumar V, Sathish T, Sarma PN (2010) Nickel-impregnated silica nanoparticle synthesis and their evaluation for biocatalyst immobilization. Appl Biochem Biotechnol 160(7):1888–1895

Article PubMed CAS Google Scholar

22. Singh P, Magalhães S, Alves L, Antunes F, Miguel M, Lindman B, Medronho B (2019) Cellulose-based edible films for probiotic entrapment. Food Hydrocoll 88:68–74

Article CAS Google Scholar

23. Qiao L, Li S, Du K (2020) Fabrication and characterization of porous cellulose beads with high strength and specific surface area via preliminary chemical cross-linking reaction for protein separation. Biochem Eng J 153:107412

Article CAS Google Scholar

24. de Mello DC (2014) Nanoparticles: workhorses of nanoscience. Springer, Berlin

Google Scholar

25. Ealia SAM, Saravanakumar M A review on the classification, characterisation, synthesis of nanoparticles and their application. In: IOP Conference Series: Materials Science and Engineering, 2017. vol 3. IOP Publishing, p 032019

26. Kruger CA, Abrahamse H (2018) Utilisation of targeted nanoparticle photosensitiser drug delivery systems for the enhancement of photodynamic therapy. Molecules 23(10):2628

Article PubMed Central Google Scholar

27. Ding S, Cargill AA, Medintz IL, Claussen JC (2015) Increasing the activity of immobilized enzymes with nanoparticle conjugation. Curr Opin Biotechnol 34:242–250

Article PubMed CAS Google Scholar

28. Bilal M, Iqbal HM (2019) Naturally-derived biopolymers: Potential platforms for enzyme immobilization. Int J Biol Macromol 130:462–482

Article PubMed CAS Google Scholar

29. Grigoras AG (2017) Catalase immobilization—a review. Biochem Eng J 117:1–20

Article CAS Google Scholar

30. de Martins OS, Moreno-Perez S, Romero-Fernández M, Fernandez-Lorente G, Rocha-Martin J, Guisan JM (2018) Immobilization and stabilization of commercial β-1, 4-endoxylanase Depol™ 333MDP by multipoint covalent attachment for xylan hydrolysis: Production of prebiotics (xylo-oligosaccharides). Biocatal Biotransfor 36(2):141–150

Article Google Scholar

31. Lokha Y, Arana-Peña S, Rios NS, Mendez-Sanchez C, Gonçalves LR, Lopez-Gallego F, Fernandez-Lafuente R (2020) Modulating the properties of the lipase from Thermomyces lanuginosus immobilized on octyl agarose beads by altering the immobilization conditions. Enzyme Microb Technol 133:109461

Article PubMed CAS Google Scholar

32. Karim A, Bibi Z, Rehman HU, Aman A, Qader SAU, Rashid MH (2021) Single step immobilization of CMCase within agarose gel matrix: Kinetics and thermodynamic studies. Colloids Surf B 200:111583

Article CAS Google Scholar

33. Serey M, Vera C, Guerrero C, Illanes A (2021) Immobilization of *Aspergillus oryzae* β-galactosidase in cation functionalized agarose matrix and its application in the synthesis of lactulose. Int J Biol Macromol 167:1564–1574

Article PubMed CAS Google Scholar

34. Lopes LA, Novelli PK, Fernandez-Lafuente R, Tardioli PW, Giordano RLC (2020) Glyoxyl-activated agarose as support for covalently link Novo-Pro D: biocatalysts performance in the hydrolysis of casein. Catalysts 10(5):466

Article CAS Google Scholar

35. Garcia-Bofill M, Sutton PW, Guillen M, Alvaro G (2021) Enzymatic synthesis of a statin precursor by immobilised alcohol dehydrogenase with NADPH oxidase as cofactor regeneration system. Appl Cat A 609:117909

Article CAS Google Scholar

36. Kamaci UD, Peksel A (2021) Enhanced catalytic activity of immobilized phytase into polyvinyl alcohol-sodium alginate based electrospun nanofibers. Cat Lett 151(3):821–831

Article Google Scholar

37. Yavaşer R, Karagözler AA (2021) Laccase immobilized polyacrylamide-alginate cryogel: a candidate for treatment of effluents. Process Biochem 101:137–146

Article Google Scholar

38. Guo R, Zheng X, Wang Y, Yang Y, Ma Y, Zou D, Liu Y (2021) Optimization of cellulase immobilization with sodium alginate-polyethylene for enhancement of enzymatic hydrolysis of microcrystalline cellulose using response surface methodology. Appl Biochem Biotechnol 193:1–18

Article Google Scholar

39. Marjani A, Zare MH, Sadeghi MH, Shirazian S, Ghadiri M (2021) Synthesis of alginate-coated magnetic nanocatalyst containing high-performance integrated enzyme for phenol removal. J Environ Chem Eng 9(1):104884

Article CAS Google Scholar

40. Qamar SA, Asgher M, Bilal M (2020) Immobilization of alkaline protease from Bacillus brevis using Ca-alginate entrapment strategy for improved catalytic stability, silver recovery, and dehairing potentialities. Cat Lett 150:3572–3583

Article CAS Google Scholar

41. Maity M, Bhattacharyya A, Bhowal J (2021) Production and immobilization of β-galactosidase isolated from *Enterobacter aerogenes* KCTC2190 by entrapment method using agar-agar organic matrix. J Appl Biochem Biotechnol. 193:1–27

Article Google Scholar

42. Irfan M, Kiran J, Ayubi S, Ullah A, Rana QUA, Khan S, Hasan F, Badshah M, Shah AA (2020) Immobilization of β-1, 4-xylanase isolated from Bacillus licheniformis S3. J

Basic Microbiol 60(7):600–612

Article PubMed CAS Google Scholar

43. Kalita T, Sangma SD, Bez G, Ambasht P (2020) Immobilization of acid phosphatase in agar-agar and gelatin: comparative characterization. J Sci Res 64(2):192–200

Google Scholar

44. Martín MC, DellÓlio GAG, Villar MA, Morata VI, López OV, Ninago MD Preparation and Characterization of an Immobilized Enological Pectinase on Agar-Alginate Beads. In: Macromolecular Symposia, 2020. vol 1. Wiley Online Library, p 1900208

45. Pervez S, Nawaz MA, Jamal M, Jan T, Maqbool F, Shah I, Aman A, Qader SAU (2019) Improvement of catalytic properties of starch hydrolyzing fungal amyloglucosidase: utilization of agar-agar as an organic matrix for immobilization. Carbohydr Res 486:107860

Article PubMed CAS Google Scholar

46. Tavares L, Flores EEE, Rodrigues RC, Hertz PF, Noreña CPZ (2020) Effect of deacetylation degree of chitosan on rheological properties and physical chemical characteristics of genipin-crosslinked chitosan beads. Food Hydrocoll 106:105876

Article CAS Google Scholar

47. Ji S, Liu W, Su S, Gan C, Jia C (2021) Chitosan derivative functionalized carbon nanotubes as carriers for enzyme immobilization to improve synthetic efficiency of ethyl caproate. LWT 149:111897

Article CAS Google Scholar

48. Srivastava B, Singh H, Khatri M, Singh G, Arya SK (2020) Immobilization of keratinase on chitosan grafted-β-cyclodextrin for the improvement of the enzyme

properties and application of free keratinase in the textile industry. Int J Biol Macromol 165:1099–1110

Article PubMed CAS Google Scholar

49. Lima PC, Gazoni I, de Carvalho AMG, Bresolin D, Cavalheiro D, de Oliveira D, Rigo E (2021) β-galactosidase from Kluyveromyces lactis in genipin-activated chitosan: An investigation on immobilization, stability, and application in diluted UHT milk. Food Chem 349:129050

Article PubMed CAS Google Scholar

50. Ricardi NC, Arenas LT, Benvenutti EV, Hinrichs R, Flores EEE, Hertz PF, Costa TMH (2021) High performance biocatalyst based on β-d-galactosidase immobilized on mesoporous silica/titania/chitosan material. J Food Chem 359:129890

Article CAS Google Scholar

51. Teepoo S, Dawan P, Barnthip N (2017) Electrospun chitosan-gelatin biopolymer composite nanofibers for horseradish peroxidase immobilization in a hydrogen peroxide biosensor. J Biosensors 7(4):47

Article Google Scholar

52. Nishida VS, de Oliveira RF, Brugnari T, Correa RCG, Peralta RA, Castoldi R, de Souza CGM, Bracht A, Peralta RM (2018) Immobilization of Aspergillus awamori β-glucosidase on commercial gelatin: an inexpensive and efficient process. Int J Biol Macromol 111:1206–1213

Article PubMed CAS Google Scholar

53. Asgher M, Noreen S, Bilal M (2017) Enhancement of catalytic, reusability, and long-term stability features of Trametes versicolor IBL-04 laccase immobilized on different polymers. Int J Biol Macromol 95:54–62

Article PubMed CAS Google Scholar

54. Zhang J, Ke W, Chen H (2020) Enhancing laccase production by white-rot fungus trametes hirsuta SSM-3 in co-culture with yeast sporidiobolus pararoseus SSM-8. Prep Biochem Biotechnol 50(1):10–17

Article PubMed CAS Google Scholar

55. Awad GEA, Ghanem AF, Wahab WAA, Wahba MI (2020) Functionalized κ-carrageenan/hyperbranched poly (amidoamine) for protease immobilization: thermodynamics and stability studies. Int J Biol Macromol 148:1140–1155

Article PubMed CAS Google Scholar

56. Wahba MI, Hassan ME, Ali KA (2021) Chitosan-glutaraldehyde activated carrageenan-alginate beads for β-D-galactosidase covalent immobilisation. J Biocat Biotransform 39(2):138–151

Article CAS Google Scholar

57. Ali AO, Abdalla MS, Shahein YE, Shokeer A, Sharada HM, Ali KA (2021) Grafted carrageenan: alginate gel beads for catalase enzyme covalent immobilization. 3 Biotech. 11(7):1–7

Article Google Scholar

58. Carneiro EA, Bastos AKP, Oliveira UMFd, Matos LJBLd, Adriano WS, Monteiro RRdC, Santos JCSd, Gonçalves LRB (2020) Improving the catalytic features of the lipase from Rhizomucor miehei immobilized on chitosan-based hybrid matrices by altering the chemical activation conditions. J Química Nova 43:1234–1239

CAS Google Scholar

59. Sannino A, Demitri C, Madaghiele M (2009) Biodegradable cellulose-based hydrogels: design and applications. Materials 2(2):353–373

Article PubMed Central CAS Google Scholar

60. Nikolic T, Korica M, Milanovic J, Kramar A, Petronijevic Z, Kostic M (2017) TEMPO-oxidized cotton as a substrate for trypsin immobilization: impact of functional groups on proteolytic activity and stability. Cellulose 24(4):1863–1875

Article CAS Google Scholar

61. Talingtaisong S, Vongsetskul T, Panatdasirisuk W, Tangboriboonrat P (2017) Gauze-reinforced electrospun regenerated cellulose ultrafine fibers for immobilizing bromelain. Cellulose 24(7):2967–2975

Article CAS Google Scholar

62. Feng Q, Hou D, Zhao Y, Xu T, Menkhaus TJ, Fong H (2014) Electrospun regenerated cellulose nanofibrous membranes surface-grafted with polymer chains/brushes via the atom transfer radical polymerization method for catalase immobilization. ACS Appl Mater Interfaces 6(23):20958–20967

Article PubMed CAS Google Scholar

63. Andrés-Bello A, Iborra-Bernad C, García-Segovia P, Martínez-Monzó J (2013) Effect of konjac glucomannan (KGM) and carboxymethylcellulose (CMC) on some physico-chemical and mechanical properties of restructured gilthead sea bream (Sparus aurata) products. Food Bioproc Tech 6(1):133–145

Article Google Scholar

64. Liu S, Zhu Y, Li W, Li Y, Li B (2016) Preparation of a magnetic responsive immobilized lipase–cellulose microgel catalyst system: role of the surface properties of the magnetic cellulose microgel. RSC Adv 6(9):7339–7347

Article CAS Google Scholar

65. Sillu D, Agnihotri S (2019) Cellulase immobilization onto magnetic halloysite nanotubes: enhanced enzyme activity and stability with high cellulose saccharification. ACS Sustain Chem Eng 8(2):900–913

Article Google Scholar

66. Rajdeo K, Harini T, Lavanya K, Fadnavis NW (2016) Immobilization of pectinase on reusable polymer support for clarification of apple juice. Food Bioprod Process 99:12–19

Article CAS Google Scholar

67. Bilal M, Iqbal HMN (2019) Sustainable bioconversion of food waste into high-value products by immobilized enzymes to meet bio-economy challenges and opportunities–A review. Food Res Int 123:226–240

Article PubMed CAS Google Scholar

68. Wu Z, Deng W, Luo J, Deng D (2019) Multifunctional nano-cellulose composite films with grape seed extracts and immobilized silver nanoparticles. Carbohydr polym 205:447–455

Article PubMed CAS Google Scholar

69. Shak KPY, Pang YL, Mah SK (2018) Nanocellulose: recent advances and its prospects in environmental remediation. Beilstein J Nanotechnol 9:2479–2498

Article PubMed PubMed Central CAS Google Scholar

70. Phanthong P, Reubroycharoen P, Hao X, Xu G, Abudula A, Guan G (2018) Nanocellulose: extraction and application. Carbon Resour Convers 1(1):32–43

Article Google Scholar

71. Kaushik M, Moores A (2016) Nanocelluloses as versatile supports for metal nanoparticles and their applications in catalysis. Green Chem 18(3):622–637

Article CAS Google Scholar

72. Markets MA (2020) Global Forecast to 2025. https://www.marketsandmarkets.com/pdfdownloadNew.asp?id=56392090. Accessed 04.03.2020 2020

73. Sharma A, Rana H, Goswami S (2021) A comprehensive review on the heavy metal removal for water remediation by the application of lignocellulosic biomass-derived nanocellulose. J Polym Environ 30:1–18

Article Google Scholar

74. Wahab RA, Elias N, Abdullah F, Ghoshal SK (2020) On the taught new tricks of enzymes immobilization: an all-inclusive overview. React Funct Polym 152:104613

Article CAS Google Scholar

75. Steen RE, Ta DT, Cortens D, Billen B, Guedens W, Adriaensens P (2013) Protein engineering for directed immobilization. Bioconjugate Chem 24(11):1761–1777

Article Google Scholar

76. Abushammala H, Mao J (2019) A review of the surface modification of cellulose and nanocellulose using aliphatic and aromatic mono-and di-isocyanates. Molecules 24(15):2782

Article PubMed Central Google Scholar

77. Vaz Graaf M, De LA, Reis RL (2003) In vitro degradation behaviour of biodegradable soy plastics: effects of crosslinking with glyoxal and thermal treatment. Polym Degradatiln Stabil. 81(65):74

Google Scholar

78. Altun GD, Cetinus SA (2007) Immobilization of pepsin on chitosan beads. Food Chem 100(964):971

Google Scholar

79. Bindu VU, Mohanan PV (2020) Thermal deactivation of α -amylase immobilized magnetic chitosan and its modified forms : a kinetic and thermodynamic study. Carbohydr Res 498:108185

Article PubMed CAS Google Scholar

80. Bezerra CS, Maria Farias C, De Sousa G, De M (2015) Enzyme immobilization onto renewable polymeric matrixes : past, present, and future trends. J Appl polym 42125(1):15. https://doi.org/10.1002/app.42125

Article CAS Google Scholar

81. Rodríguez-Restrepo YA, Orrego CE (2020) Immobilization of enzymes and cells on lignocellulosic materials. Environ Chem Lett 18(3):787–806

Article Google Scholar

82. Kontturi E, Laaksonen P, Linder MB, Gröschel AH, Rojas OJ, Ikkala O (2018) Advanced materials through assembly of nanocelluloses. Adv Mater 30(24):1703779

Article Google Scholar

83. Incani V, Danumah C, Boluk Y (2013) Nanocomposites of nanocrystalline cellulose for enzyme immobilization. Cellulose 20(1):191–200

Article CAS Google Scholar

84. Eibinger M, Sattelkow J, Ganner T, Plank H, Nidetzky B (2017) Single-molecule study of oxidative enzymatic deconstruction of cellulose. Nat commun 8(1):1–7

Article CAS Google Scholar

85. Liu Y, Chen JY (2016) Enzyme immobilization on cellulose matrixes. J Bioact Compat Polym 31(6):553–567

Article CAS Google Scholar

86. Costa-Silva TA, Souza CRF, Said S, Oliveira WP (2015) Drying of enzyme immobilized on eco-friendly supports. Afr J Biotechnol 14(44):3019–3026

Article CAS Google Scholar

87. Sunasee R, Hemraz UD, Ckless K (2016) Cellulose nanocrystals: a versatile nanoplatform for emerging biomedical applications. Expert Opin Drug Deliv 13(9):1243–1256

Article PubMed CAS Google Scholar

88. Uth C, Zielonka S, Hörner S, Rasche N, Plog A, Orelma H, Avrutina O, Zhang K, Kolmar H (2014) A chemoenzymatic approach to protein immobilization onto crystalline cellulose nanoscaffolds. Angew Chem Int Ed 53(46):12618–12623

CAS Google Scholar

89. Schyrr B, Pasche S, Voirin G, Weder C, Simon YC, Foster EJ (2014) Biosensors based on porous cellulose nanocrystal–poly (vinyl alcohol) scaffolds. ACS Appl Mater Interfaces 6(15):12674–12683

Article PubMed CAS Google Scholar

90. Valo H, Arola S, Laaksonen P, Torkkeli M, Peltonen L, Linder MB, Serimaa R, Kuga S, Hirvonen J, Laaksonen T (2013) Drug release from nanoparticles embedded in four different nanofibrillar cellulose aerogels. Eur J Pharm Sci 50(1):69–77

Article PubMed CAS Google Scholar

91. Fritz C, Jeuck B, Salas C, Gonzalez R, Jameel H, Rojas OJ (2015) Nanocellulose and proteins: exploiting their interactions for production, immobilization, and synthesis of biocompatible materials. Cellul Chem Prop. 271(207):224

Google Scholar

92. Fu LH, Qi C, Liu YJ, Cao WT, Ma MG (2018) Sonochemical synthesis of cellulose/hydroxyapatite nanocomposites and their application in protein adsorption. Sci Rep 8(1):1–12

Article Google Scholar

93. Lim EK, Chung BH (2016) Preparation of pyrenyl-based multifunctional nanocomposites for biomedical applications. Nat prot 11(2):236–251

Article CAS Google Scholar

94. Alonso-Lerma B, Barandiaran L, Ugarte L, Larraza I, Reifs A, Olmos-Juste R, Barruetabeña N, Amenabar I, Hillenbrand R, Eceiza A (2020) High performance crystalline nanocellulose using an ancestral endoglucanase. Commun Mater 1(1):1–10

Article Google Scholar

95. Rosa L, Blackledge J, Boretti A (2017) Nano-magnetic resonance imaging (nano-MRI) gives personalized medicine a new perspective. Biomedicines 5(1):7

Article PubMed Central Google Scholar

96. Petropoulou A, Kralj S, Karagiorgis X, Savva I, Loizides E, Panagi M, Krasia-Christoforou T, Riziotis C (2020) Multifunctional gas and pH fluorescent sensors based on cellulose acetate electrospun fibers decorated with rhodamine B-functionalised core-shell ferrous nanoparticles. Sci rep 1(1):1–14

Google Scholar

97. Lin X, Han X, Wang J (2018) In situ synthesis of easily separable Au nanoparticles catalysts based on cellulose hydrogels. Polym J 50(7):495–501

Article CAS Google Scholar

Acknowledgements

The authors would like to acknowledge Center of Innovative and Applied Bioprocessing (CIAB), Mohali for equipment and Infrastructure facilities. They would like to acknowledge Department of Biotechnology (DBT), India for source of funding agencies.

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Contributions

All authors contributed to the study conception and design. HR and SD: Material preparation, data collection and analysis were performed. The first draft of the manuscript was written by HR and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Ethics declarations

Conflict of interest

Authors have no conflict of interest to disclose in any capacity either competing or financial.

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Cite this article

Rana, H., Sharma, A., Dutta, S. *et al.* Recent Approaches on the Application of Agro Waste Derived Biocomposites as Green Support Matrix for Enzyme Immobilization. *J Polym Environ* **30**, 4936–4960 (2022). https://doi.org/10.1007/s10924-022-02574-3

Accepted	Published	Issue Date
25 August 2022	14 September 2022	December 2022

DOI

https://doi.org/10.1007/s10924-022-02574-3

Keywords

- CNC
- Immobilization
- Nanocellulose-protein interaction
- Surface modification
- Support Matrix