The Bioscan AN INTERNATIONAL QUARTERLY JOURNAL OF LIFE SCIENCES 20(2): S2: 1021-1026, 2025 www.thebioscan.com

FABRICATION AND CHARACTERIZATION OF PECTIN/POLYVINYL ALCOHOL BIO-COMPOSITE FOR ENHANCED ANTIMICROBIAL ACTIVITY

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DOI: 10.63001/tbs.2025.v20.i02.S2.pp1021-1026

KEYWORDS
polysaccharide, bio-composite, antimicrobial, biodegradable

Received on:

02-05-2025

Accepted on:

06-06-2025

Published on:

11-07-2025

ABSTRACT

The blending of natural polysaccharide pectin with synthetic biodegradable polymer polyvinyl alcohol (PVA) aimed to develop a bio-composite with improved functional and structural properties. The bio-composite was fabricated through solution casting method, and its physicochemical characteristics were analysed using techniques such as FTIR, XRD, SEM and antimicrobial activity. FTIR analysis confirmed the successful interaction and hydrogen bonding between the functional groups of Pectin and PVA. XRD studies showed a reduction in crystallinity, indicating effective blending and partial amorphization of the bio-composite matrix. SEM analysis revealed the surface morphology of the prepared bio-composite and suggesting the strong interfacial compatibility between Pectin and PVA . Antimicrobial activity was assessed against common bacterial strains, and the bio-composite exhibited significant inhibitory effects, especially due to the bioactive nature of pectin and its synergistic interaction with PVA. These findings demonstrate that Pectin/PVA bio-composite hold promising potential for applications in antimicrobial packaging and biomedical materials.

INTRODUCTION

In plants and animals, some natural polymers such as chitin, pectin and cellulose are essential for maintaining the structural integrity of cells [1]. These natural polymers have unique physicochemical and biological characteristics that can be useful in a variety of disciplines due to their diversity in composition and provenance [2-3]. Proteins, nucleic acids, and polysaccharides are part of biological systems and carry out a variety of vital tasks [4]. Indeed, natural polymers and their derivatives are already used in many industries for the production of textiles[5] and paper goods [6], as food additives [7-9], in the creation of nutraceuticals and functional foods [10], and in the biomedical industry for drug delivery [11-12] and cosmetic procedures[13].

All plants that grow on land contain pectin, a type of naturally occurring polymer. They are present in plant cell walls, where they serve as a binder, hydrator, and structural component for the network of cellulose fibers [14-15]. Pectin are plentiful in apple pomace and citrus albedo, which are essential raw materials used in the production of pectin all over the world [16]. When pectin is properly mixed with water and/or other chemicals, it can serve as a thickener, stabiliser, gelling agent, emulsifier, cation-binding agent etc [17]. The need to create renewable and biodegradable materials to lessen the amount of non-renewable petroleum-based waste in landfills has led to a recent surge in research on pectin-based products [18]. However, there are a few disadvantages to pure pectin-based films, such as their poor moisture and gas barrier qualities, brittleness, and low mechanical strength. Pectin's barrier qualities may be enhanced by combining it with other polymers, such as chitosan, starch, polyethylene glycol, polylactic acid, polyvinyl alcohol, natural proteins, etc., or by adding hydrophobic substances, like essential oils, to the polymer matrix [19]. It has a promising future as a customized, versatile biomaterial. Because of its cytocompatibility, it has been utilized for a number of biomedical applications, including tissue engineering, medication administration, gene transport, and wound healing. Additionally, pectin-based coatings are utilized to extend the shelf life of certain fruits [20-21].

PVA is another important biodegradable polymer that finds uses in a wide range of commercial, pharmaceutical, industrial, and food applications as eyedrops, lacquers, resins, tablet coating agents, paper coating agents, and food packaging materials.

Additionally, it can be used with water-soluble fabric to create surgical threads, rags, sponges, sheets, covers, hospital laundry bags, biodegradable protective clothing, and other physiological sanitization products. It provides good stiffness when employed as a sizing and coating agent with paper, which makes it beneficial for applications such as lamination, carton sealing, and winding [22]. Because of their low cost, superior mechanical strength, strong barrier qualities, and ease of processing, petrochemical-based polymers are typically utilized in food packaging applications. But when disposed of, they cause serious environmental problems because they are not biodegradable. Eco-friendly packing materials are therefore highly sought after [23].

Polymer blending is an effective route for preparing desired polymeric materials for a wide range of tailor-made applications. Pectin is miscible in all proportions with polyvinyl alcohol resulting in miscible blends. Proposed uses for Pectin/PVA films include flushable liners and bags, water-soluble detergent and pesticide pouches, drug delivery aids and wound dressing materials [24]. PVA, starch, and Pectin combined with glycerol as a plasticizer is said to provide environmentally friendly films with better qualities [25]. It is reported PVA/starch-based biodegradable nanocomposite films reinforced with starch nanocrystals were considered as potential alternative for synthetic packaging material [26]. PVA based biodegradable nano composite film reinforced with coconut cellulose nano fiber was prepared as a better alternative to synthetic plastic food packaging. Essential oils like lemon oil and linseed oil were also incorporated into the prepared film to get the antimicrobial properties to the packaging film [27,28].

2. EXPERIMENTAL PROCEDURE

2.1 MATERIALS

Pectin, PVA and glycerol were procured from Sigma Aldrich.

2.2 PREPARATION OF PECTIN/PVA BIO-COMPOSITE

The Pectin/PVA bio-composite was developed using the solvent casting method. 0.5 g of Pectin was dissolved in 20 ml distilled water and 0.15 g of PVA was dissolved in 10 ml distilled water and the solutions were mixed thoroughly with 0.6 g of glycerol. The resultant mixture was then vigorously stirred at 70 °C for two hours at 800 rpm. The resulting homogeneous mixture was poured onto a mould and allowed to dry in an oven at 45 °C. The bio-composite film was carefully peeled off and stored in a desiccator for further characterization and analysis.

2.3 CHARACTERISATION

The FTIR spectrum of Pectin/PVA bio-composite was recorded using a Thermo Nicolet iS50. The samples were mixed with KBr powder and then pressed into thin pellets. The sample's wavelength range was measured between 4000 and 400 cm^{-1}. With the aid of a Bruker D4 X-ray diffractometer, the resulting crystallinity index was examined. The measurement was done with Cu Kα radiation at 40 kV. With an acceleration voltage range of 0.5 to 30 kV, the JEOL 6390LA/OXFORD XMX N apparatus was used to take the microscopy SEM images. A detector of secondary electrons (SE) was used to take the pictures. Kirby-Bauer test is widely used to determine the sensitivity or resistance of bacteria and fungi to various antimicrobial compounds, and it uses the Mueller Hinton agar. Mueller-Hinton agar is a non-selective, non-differential medium capable of growing a wide range of non-fastidious organisms. Kirby-Bauer test is also known as disk diffusion method.

3. RESULTS AND DISCUSSIONS

3.1 FTIR SPECTRAL ANALYSIS

The existence and interaction of functional groups from both polymers were confirmed by a number of distinctive absorption bands in the Pectin/PVA blend, as shown in Fig.1. The stretching vibrations of hydroxyl (OH) groups were represented by a broad and strong band at about 3348 cm^{-1}. This broad peak was characteristic of intramolecular hydrogen bonding between the hydroxyl groups of PVA and the hydroxyl groups present in pectin, which suggested significant hydrogen bonding. Aliphatic C-H bonds asymmetric stretching was responsible for the peak at 2921 cm^{-1}. A weaker peak at about 2372 cm^{-1} was caused by small C≡C, whereas the sharp band seen at 1620 cm^{-1} was attributed to the stretching vibrations of carbonyl (C=O) groups from Pectin's ester or carboxylic acid functionality. C–O–C stretching vibrations, which were characteristic of either and polysaccharide structures, were linked to peaks that fell between 1402 cm^{-1} and 1035 cm^{-1}. The peak at 887 cm^{-1} correlated to sugar ring skeletal vibrations and C–H bending, demonstrating pectin's polysaccharide origin and its excellent integration with PVA. Overall, the blend's compatibility and strong intermolecular hydrogen bonding were shown by the broadening and minor peak changes.

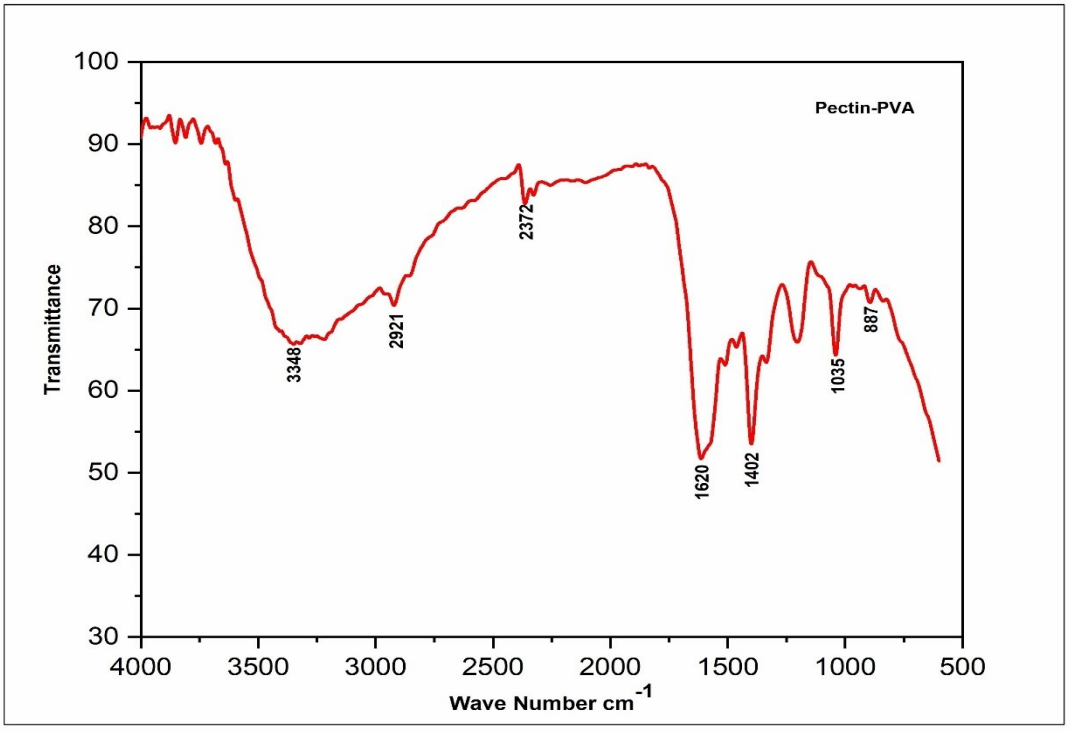

Fig.1: FTIR spectrum of Pectin/PVA bio-composite

3.2 XRD ANALYSIS

The XRD pattern of the Pectin/PVA bio-composite, as shown in Fig.2, exhibited a broad and diffused peak without any sharp crystalline reflections, which was indicative of an amorphous structure. The broad hump observed between approximately 15° and 30° (2θ) suggested the presence of disordered regions within the polymer matrix. This amorphous nature could be attributed to the intermolecular hydrogen bonding and molecular entanglement between the hydroxyl groups of PVA and the functional groups of pectin, which disrupted the crystalline order of individual components. The absence of sharp peaks confirmed that the blending of pectin and PVA resulted in a predominantly non-crystalline material, which was beneficial for certain applications such as drug delivery, food packaging, and wound dressings, where flexibility, biodegradability, and uniform film-forming ability were desired.

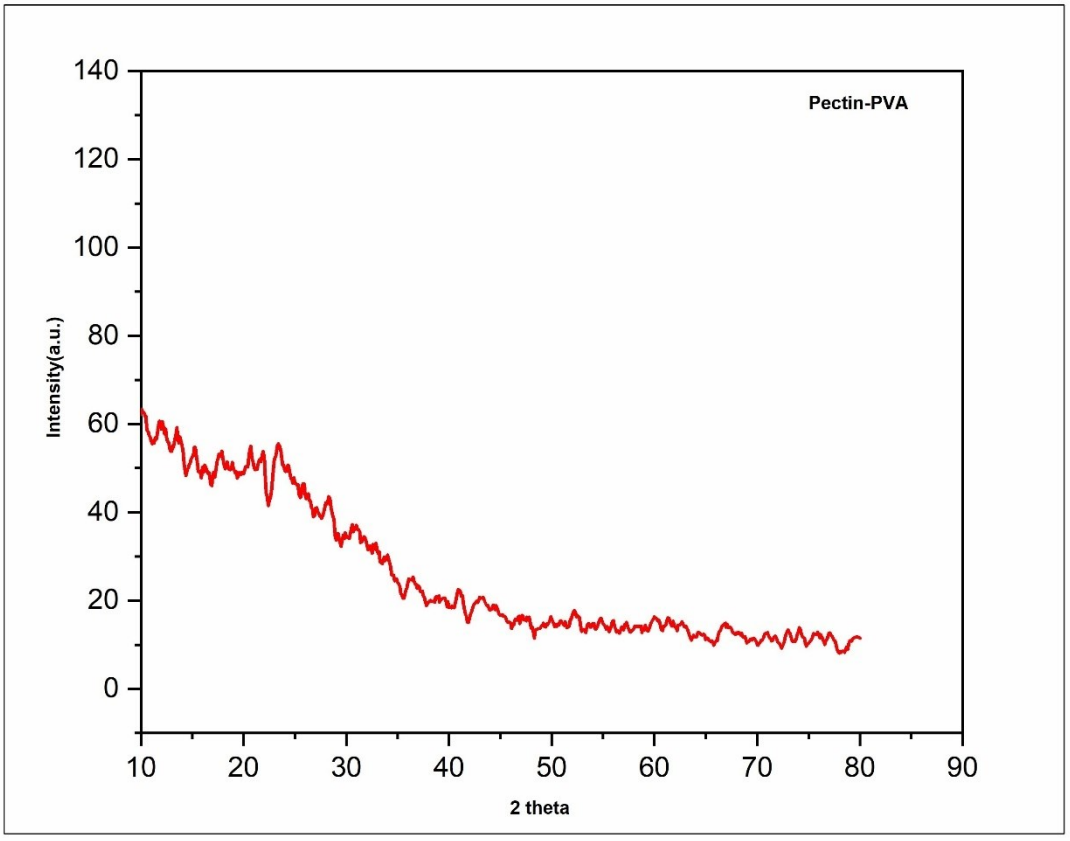

Fig.2: XRD Pattern of Pectin/PVA bio-composite

3.3 SEM ANALYSIS

The surface morphology of the Pectin/PVA bio-composite was shown in Fig.3. It showed a rough, uneven surface with areas of different textures, suggesting phase separation or insufficient mixing of the PVA and Pectin components. A flexible, polymeric matrix was present in wrinkled and folded areas, whereas denser agglomerates or crystalline domains from PVA crystallites were represented by bright, elevated characteristics. The lengthy, pillar-like structure close to the middle could have represented a flaw or impurity that developed during the drying or casting of the film. The image generally pointed to a non-uniform microstructure, which may have had an impact on the mechanical characteristics, barrier behavior and biodegradability of the bio-composite.

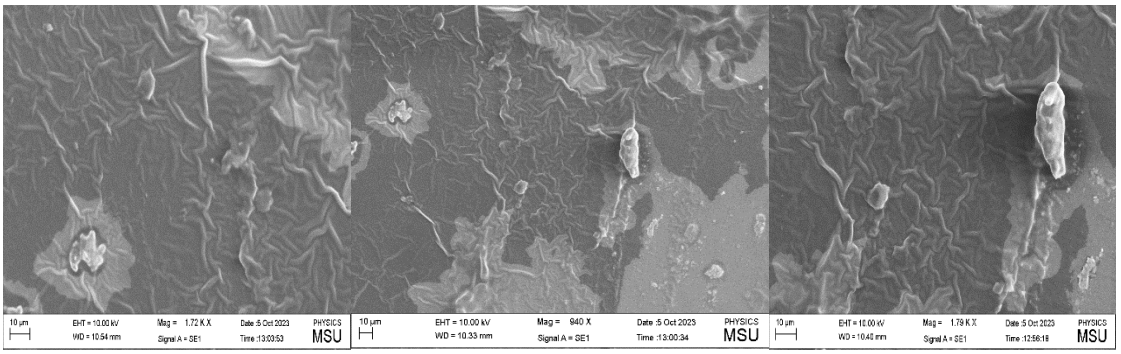

Fig.3: SEM images of Pectin/PVA bio-composite

3.4 ANTIBACTERIAL STUDY OF PECTIN/PVA BIO-COMPOSITE

The antibacterial activity of the Pectin/PVA bio-composite was evaluated against four bacterial strains: Escherichia coli, Proteus vulgaris, Bacillus subtilis, and Staphylococcus aureus, and compared with a standard antibiotic control (Amikacin) (Table 1). The bio-composite exhibited a larger zone of inhibition (18 mm) against E. coli than the control (16 mm), indicating strong antibacterial potential against the Gram-negative bacterium. Similarly, for Staphylococcus aureus, the bio-composite showed a 17 mm zone compared to the control's 15 mm, demonstrating

effective activity against this Gram-positive bacterium. Against Bacillus subtilis, the bio-composite recorded a 15 mm zone, slightly higher than the 14 mm of the control, suggesting comparable efficacy. However, for Proteus vulgaris, the composite showed a slightly lower zone (16 mm) than the control (17 mm), though still demonstrating inhibitory activity. The enhanced antibacterial effect of the Pectin/PVA bio-composite (Fig. 4) was attributed to the presence of bioactive compounds in pectin and the film-forming ability of PVA, which together could disrupt bacterial cell membranes and inhibit growth. Overall, the bio-composite showed promising antibacterial properties, making it a potential candidate for applications in wound dressings, food packaging, and biomedical materials.

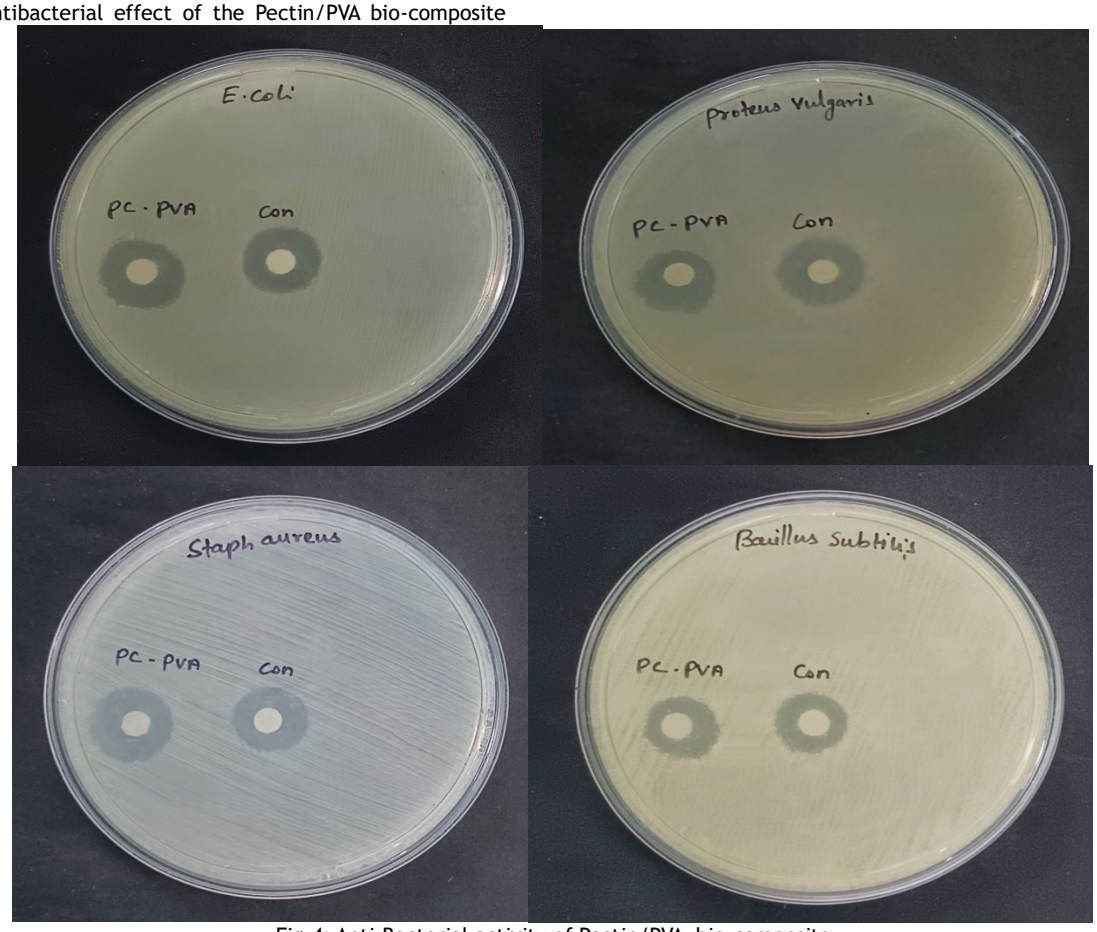

Fig.4: Anti-Bacterial activity of Pectin/PVA bio-composite

Bacteria	PECTIN-PVA Bio-Composite	Control (amikacin)
Escherichia coli	18mm	16mm
Proteus vulgaris	16mm	17mm
Bacillus subtilis	15mm	14mm
Staph aureus	17mm	15mm

Table 2: Antibacterial activities of Pectin/PVA bio-composite

3.5 ANTIFUNGAL ACTIVITIES OF PECTIN/PVA BIO-COMPOSITE

The antifungal activity of the Pectin/PVA bio-composite was evaluated against two fungal strains: Candida albicans and Aspergillus niger, and compared with a standard antifungal agent, Nystatin (Table 2). The zone of inhibition observed for Candida albicans was 14 mm for both the Pectin-PVA bio-composite and the control, indicating that the bio-composite exhibited comparable antifungal efficacy to Nystatin against this yeast. Interestingly, against Aspergillus niger, the Pectin/PVA bio-composite showed a slightly larger inhibition zone of 15.2 mm, compared to 13 mm with the control, suggesting enhanced antifungal activity, which was shown in Fig. 5. This increased efficacy may have been attributed to the synergistic interaction between pectin and PVA, which could have enhanced the diffusion of active components and disrupted fungal cell walls more effectively. Overall, the Pectin/PVA bio-composite demonstrated promising antifungal potential, especially against filamentous fungi like Aspergillus niger.

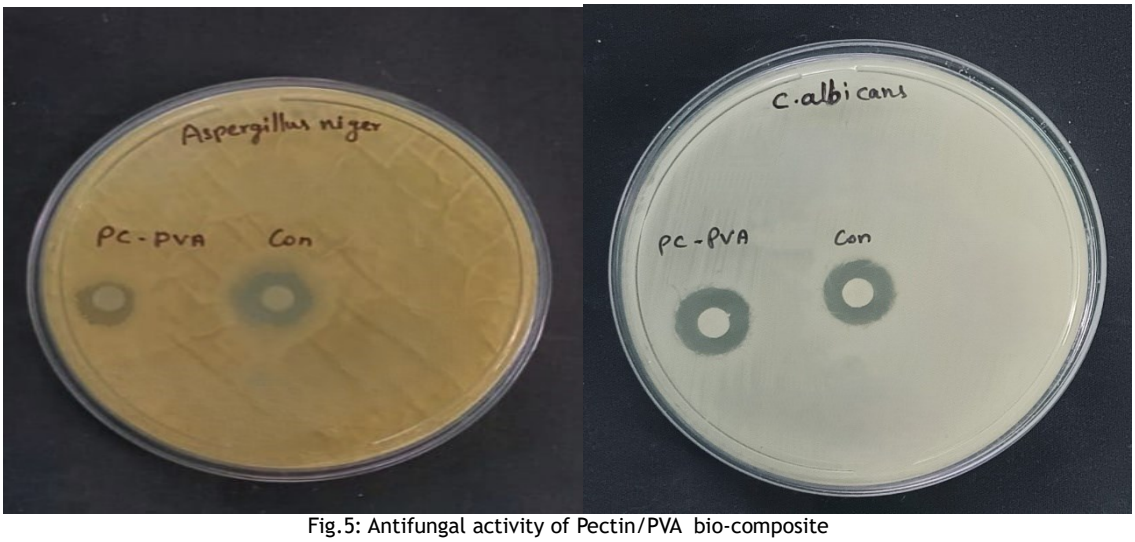

Fig.5: Antifungal activity of Pectin/PVA bio-composite

Fungus	PECTIN-PVA bio-composite	Control (Nystatin)
Candida albicans	14mm	14mm
Aspergillus niger	15.2mm	13mm

Table 3: Antifungal activities of Pectin/PVA bio-composite

CONCLUSION

The bio-composite developed by the solution casting of Pectin and PVA had promising structural and functional characteristics. FTIR analysis indicates the presence and interaction of functional groups from both components. The SEM analysis of the Pectin/PVA bio-composite shows an uneven and rough surface morphology, indicating partial miscibility and phase separation between the polymers. The composite's amorphous character, as revealed by the XRD data, facilitates the breakdown of crystalline areas by polymer interactions, improving flexibility and film-forming capabilities. A promising option for biomedical and antimicrobial packaging applications, the bio-composite had notable inhibitory effects against both Gram-positive and Gram-negative bacteria, according to the antibacterial experiments. Overall, the Pectin/PVA bio-composite presents a sustainable, biodegradable material with multifunctional properties, and with further refinement, it holds strong promise for diverse applications in the medical and environmental fields.

REFERENCES

- [1] Klemm D., Heublein B., Fink H.-P., Bohn A. Cellulose: Fascinating Biopolymer and Sustainable Raw Material. Angew. Chem. Int. Ed. 2005;44:3358–3393. doi:10.1002/anie.200460587.
- [2] Vilela C., Pinto R.J.B., Pinto S., Marques P.A.A.P., Silvestre A.J.D., Freire C.S.R. Polysaccharide Based Hybrid Materials: Metals and Metal Oxides, Graphene and Carbon Nanotubes. 1st ed. Springer International Publishing; Cham, Switzerland: 2018. Springer Briefs in Molecular Science.
- [3] Silva N.H.C.S., Vilela C., Marrucho I.M., Freire C.S.R., Neto C.P., Silvestre A.J.D. Protein-Based materials: From sources to innovative sustainable materials for biomedical applications. J. Mater. Chem. B. 2014;2:3715–3740. doi: 10.1039/c4tb00168k.
- [4] Yu L., Chen L. Polymeric materials from renewable resources. In: Yu L., editor. Biodegradable Polymer Blends and Composites from Renewable Resources. John Wiley & Sons, Ltd.; Hoboken, NJ, USA: 2009. pp. 1–15.
- [5] Silva A.C.Q., Silvestre A.J.D., Freire C.S.R., Vilela C. Modification of textiles for functional applications. In: Mondal M.I.H., editor. Fundamentals of Natural Fibres and Textiles. Woodhead Publishing, Elsevier Ltd.; Amsterdam, The Netherlands: 2021. pp. 303–365.
- [6] Basu S., Malik S., Joshi G., Gupta P., Rana V. Utilization of bio-polymeric additives for a sustainable production strategy in pulp and paper manufacturing: A comprehensive review. Carbohydr. Polym. Technol. Appl. 2021;2:100050. doi: 10.1016/j.carpta.2021.100050.
- [7] Hu C., Lu W., Mata A., Nishinari K., Fang Y. Ions-Induced gelation of alginate: Mechanisms and applications. Int. J. Biol. Macromol. 2021;177:578–588. doi: 10.1016/j.ijbiomac.2021.02.086.
- [8] Mostafavi F.S., Zaeim D. Agar-Based edible films for food packaging applications—A review. Int. J. Biol. Macromol. 2020;159:1165–1176. doi: 10.1016/j.ijbiomac.2020.05.123.
- [9] Alipal J., Pu'Ad N.M., Lee T., Nayan N., Sahari N., Basri H., Idris M., Abdullah H. A review of gelatin: Properties, sources, process, applications, and commercialisation. Mater. Today Proc. 2021;42:240–250. doi: 10.1016/j.matpr.2020.12.922.
- [10] Zhao Y., Zheng Y., Wang J., Ma S., Yu Y., White W.L., Yang S., Yang F., Lu J. Fucoidan Extracted from Undaria pinnatifida: Source for Nutraceuticals/Functional Foods. Mar. Drugs. 2018;16:321. doi: 10.3390/md16090321.
- [11] Gradishar W.J., Tjulandin S., Davidson N., Shaw H., Desai N., Bhar P., Hawkins M., O'Shaughnessy J. Phase III Trial of Nanoparticle Albumin-Bound Paclitaxel Compared with Polyethylated Castor Oil–Based Paclitaxel in Women with Breast Cancer. J. Clin. Oncol. 2005;23:7794–7803. doi: 10.1200/JCO.2005.04.937.
- [12] Tong X., Pan W., Su T., Zhang M., Dong W., Qi X. Recent advances in natural polymer-based drug delivery systems. React. Funct. Polym. 2020;148:104501. doi: 10.1016/j.reactfunctpolym.2020.104501.
- [13] Bukhari S.N.A., Roswandi N.L., Waqas M., Habib H., Hussain F., Khan S., Sohail M., Ramli N.A., Thu H.E., Hussain Z. Hyaluronic acid, a promising skin rejuvenating biomedicine: A review of recent updates and pre-clinical and clinical investigations on cosmetic and nutricosmetic effects. Int. J. Biol. Macromol. 2018;120:1682–1695. doi: 10.1016/j.ijbiomac.2018.09.188.
- [14] C. Rolin, J.D. Vries Pectin Food Gels, Springer, Dordrecht (1990), pp. 401-434

- [15] B.R. Thakur, R.K. Singh, A.K. Handa, M.A. Rao Chemistry and uses of pectin—a review Crit. Rev. Food Sci. Nutr., 37 (1) (1997), pp. 47-73
- [16] M.H. Canteri-Schemin, H.C.R. Fertonani, N. Waszczynskyj, G. Wosiacki Extraction of pectin from apple pomace Braz. Arch. Biol. Technol., 48 (2005), pp. 259-266
- [17] N.M. Ptichkina, O.A. Markina, G.N. Rumyantseva Pectin extraction from pumpkin with the aid of microbial enzymes Food Hydrocolloids, 22 (1) (2008), pp. 192-195
- [18] D.R. Coffin, M.L. Fishman Physical and mechanical properties of highly plasticized pectin/starch films J. Appl. Polym. Sci., 54 (9) (1994), pp. 1311-1320
- [19] A.C. Mellinas, A. Jiménez, M.C. Garrigós Pectin-based films with cocoa bean shell waste extract and ZnO/Zn-NPs with enhanced oxygen barrier, ultraviolet screen and photocatalytic properties Foods, 9 (11) (2020), p. 1572
- [20] F.A.B.I. Munarin, M.C. Tanzi, P.A.O.L.A. Petrini Advances in biomedical applications of pectin gels Int. J. Biol. Macromol., 51 (4) (2012), pp. 681-689
- [21]A. Al-Asmar, C.V.L. Giosafatto, M. Sabbah, A. Sanchez, R. Villalonga Santana, L. Mariniello Effect of mesoporous silica nanoparticles on the physicochemical properties of pectin packaging material for strawberry wrapping Nanomaterials, 10 (1) (2019), p. 52
- [22] C.C. DeMerlis, D.R. Schoneker Review of the oral toxicity of polyvinyl alcohol (PVA) Food Chem. Toxicol., 41 (3) (2003), pp. 319-326
- [23] B. Lekhasree, E. Muthusankar, S.V. Kumar ZNO/Cellulose Nano Whiskers Reinforced Pectin for Antimicrobial Food Packaging (2021)
- [24] C. Jo, H. Kang, N.Y. Lee, J.H. Kwon, M.W. Byun, Pectin-and gelatin-based film: effect of gamma irradiation on the mechanical properties and biodegradation, Radiat. Phys. Chem. 72 (6) (2005) 745–750
- [25] S. Lal, V. Kumar, S. Arora, Eco-friendly synthesis of biodegradable and high strength ternary blend films of PVA/starch/pectin: mechanical, thermal and biodegradation studies, Polym. Polym. Compos. 29 (9) (2021) 1505–1514.
- [26] A. Mittal, S. Garg, A. Premi, A.S. Giri, Synthesis of polyvinyl alcohol/modified starch-based biodegradable nanocomposite films reinforced with starch nanocrystals for packaging applications, Polym. Polym. Compos. 29 (5) (2021) 405–416.
- [27] R. Arun, R. Shruthy, R. Preetha, V. Sreejit, Biodegradable nano composite reinforced with cellulose nano fiber from coconut industry waste for replacing synthetic plastic food packaging, Chemosphere 291 (2022), 132786.
- [28] A.A. Oun, G.H. Shin, J.W. Rhim, J.T. Kim, Recent advances in polyvinyl alcohol-based composite films and their applications in food packaging, Food Packag. Shelf Life 34 (2022), 100991.