E-ISSN: 2829-7687
Journal of Fibers and Polymer Composites
Vol. 5 No. 1 (2026): 19-30

Modified PVA Film from Methanol-Soluble Phenolic Extracts of Spatholobus littoralis Hask as Active Pharmaceutical Packaging

Kadriadi [a b c], Hairul Abral [a b d]*, Melbi Mahardika [d e]*, Ilhamdi [a], Akmal [a], Dian Handayani [f], Yulianis [f], Mohamad Haafiz Mohamad Kassim [g h], Jeri Ariksa [a i]

[a] Department of Mechanical Engineering, Universitas Andalas, Padang, Indonesia
[b] Laboratory of Nanoscience and Technology, Department of Mechanical Engineering, Universitas Andalas, Padang, Indonesia
[c] Department of Mechanical Maintenance Engineering, Politeknik Industri Logam Morowali, Morowali, Indonesia
[d] Research Collaboration Center for Nanocellulose, BRIN and Universitas Andalas, Padang, Indonesia
[e] Research Center for Biomass and Bioproducts, National Research and Innovation Agency of Indonesia (BRIN), South Tangerang, Indonesia
[f] Laboratory of Sumatran Biota, Faculty of Pharmacy, Universitas Andalas, Padang, Indonesia
[g] Bioresource Technology Division, School of Industrial Technology, Universiti Sains Malaysia, Penang, Malaysia
[h] Green Biopolymer, Coatings & Packaging Cluster, School of Industrial Technology, Universiti Sains Malaysia, Penang, Malaysia
[i] Department of Mechanical Engineering, Bangka Belitung University, Bangka, Indonesia

Abstract. *The development of active pharmaceutical packaging based on biodegradable materials is an important strategy to reduce dependence on single-use plastics and their environmental impact. Polyvinyl alcohol (PVA) is a potential biodegradable polymer, but it has limitations in terms of exposure to ultraviolet (UV) radiation and microbial contamination. This study aims to develop a modified PVA film with methanol-soluble phenolic extract of Spatholobus littoralis Hask as active pharmaceutical packaging with UV protection, antioxidant, and antibacterial functions. The phenolic extract was obtained through a maceration method using methanol as a solvent, while the PVA film was fabricated using the solution casting technique. The PVA film was modified with varying concentrations of phenolic extract of 0, 1.25, 2.5, and 5wt% (PPE0, PPE1.25, PPE2.5, and PPE5), then evaluated for its UV protection properties, antioxidant activity, and antibacterial activity. The results showed that the addition of S. littoralis phenolic extract was able to increase the ability of PVA films to block UV radiation completely (100%) in the 200–400 nm wavelength range. Antioxidant activity testing using the DPPH method showed an increase in free radical scavenging ability as the concentration of phenolic extract increased. In addition, the modified PVA film showed significant antibacterial activity against Staphylococcus aureus and Escherichia coli. These findings indicate that S. littoralis Hask phenolic extract has potential as a natural bioactive agent in the development of environmentally friendly and multifunctional active pharmaceutical packaging, with dual protection capabilities against UV degradation and microbial contamination. This research makes an important contribution to the development of sustainable pharmaceutical packaging materials based on renewable natural resources.*

Keywords: *Polyvinyl Alcohol (PVA) Film; Phenolic Extract; Pharmaceutical Packaging; UV Protection; Antibacterial Activity.*

Type of the Paper: Regular Article.

https://doi.org/10.55043/jfpc.v5i1.567
Received February 5, 2026; Received in revised form February 10, 2026; Accepted February 14, 2026; ARTICLE IN PRESS
* First corresponding author
Email: melbimahardika@gmail.com

1. Introduction

The pharmaceutical industry is experiencing rapid growth in response to increasing demands for safer, more efficient, and sustainable packaging systems. One of the major challenges currently faced is the extensive use of single-use plastics, which contributes significantly to global environmental pollution and may adversely affect the quality and stability of pharmaceutical products. The widespread application of petroleum-based plastics in pharmaceutical packaging poses serious environmental concerns due to their non-biodegradable nature and prolonged persistence in the environment, leading to the accumulation of plastic waste [1,2]. As global awareness of environmental sustainability continues to increase, the development of environmentally friendly packaging alternatives that can comply with the stringent requirements of pharmaceutical applications has become increasingly urgent [3,4].

Biodegradable polymers, such as polyvinyl alcohol (PVA), are increasingly being developed as potential alternatives to conventional plastics. PVA is a synthetic polymer that is water-soluble and known to have high levels of biodegradability, biocompatibility, and flexibility, making it very suitable for use as a packaging material [5,6]. This material has been widely used in various industrial sectors, including the pharmaceutical field, particularly in the manufacture of film coatings, drug delivery systems, and packaging materials. PVA's ability to degrade naturally without producing harmful residues makes it an attractive option in the development of sustainable materials [7]. However, PVA has limitations, mainly due to its sensitivity to environmental factors such as exposure to ultraviolet (UV) radiation and microbial attack, which can limit its application in certain conditions [8,9]. In the context of pharmaceutical packaging, material durability and protection against external influences are crucial to ensure the quality, safety, and effectiveness of packaged products [10].

One method that can be used to improve the performance of PVA films is to modify them using natural bioactive compounds, such as phenolic extracts derived from plants [11,12]. Phenolic compounds are known to have antioxidant activity [13]. They also have the ability to absorb ultraviolet (UV) radiation [14,15]. In addition, phenolic compounds also have antimicrobial properties. This makes them very promising for use in various fields, including food preservation, cosmetic products, and pharmaceutical packaging [16,17]. Previous studies have demonstrated that the incorporation of plant-derived bioactive compounds into PVA films can significantly enhance their functional properties. The addition of Uncaria gambir extract has been reported to provide effective ultraviolet protection to PVA-based films [18]. Similarly, the incorporation of tannin compounds has been shown to improve the antioxidant activity of PVA films [19]. Furthermore, the integration of tea polyphenols into the PVA matrix has been reported to impart antimicrobial properties to the resulting films [20]. However, differences in the solubility of

bioactive extracts prior to mixing with PVA affect the functional characteristics of the modified film.

Previous studies have shown methods of combining bioactive compounds with PVA matrices. PVA films modified with bioactive extracts from bay leaves dissolved in methanol improve UV blocking, antioxidant, and antibacterial properties [21]. This study focuses on the use of Spatholobus littoralis Hask (Bajakah Tampala), a plant found in Southeast Asia, especially in the forests of Kalimantan, Indonesia. This plant was chosen because of its high content of bioactive compounds, such as flavonoids and phenolic acids [22]. These bioactive compounds are known for their high antioxidant and antimicrobial activity, as well as their ability to effectively absorb ultraviolet radiation [16,23]. Therefore, the addition of Bajakah Tampala phenolic extract to PVA film with methanol as a solvent is expected to improve the performance of pharmaceutical packaging by providing double protection against UV exposure and microbial contamination.

To the best of the authors' knowledge, there have been no reported studies on the development of modified poly (vinyl alcohol) (PVA) films incorporating phenolic extracts from Spatholobus littoralis Hask dissolved in methanol. Accordingly, this study offers a novel approach to the development of active pharmaceutical packaging materials that require enhanced functional performance. The objective of this work is to fabricate PVA films enriched with Spatholobus littoralis Hask phenolic extract (PE) as a bioactive component to address the increasing demand for pharmaceutical packaging with additional functional properties. This study systematically investigates the potential of Spatholobus littoralis Hask phenolic extract to improve the characteristics of PVA films, particularly in terms of ultraviolet radiation shielding, antioxidant activity, and antibacterial efficacy. Furthermore, by evaluating the performance of modified films at various phenolic extract concentrations (0, 0.125, 2.5, and 5 wt%), this study aims to identify the optimal loading level that maximizes functional enhancement while preserving the suitability of the films for pharmaceutical packaging applications. The selected concentration range was designed to enable a comprehensive assessment of the effect of phenolic extract content on film performance and to determine the most effective formulation.

2. Materials and Methods

2.1 Materials

Spatholobus littoralis Hassk. (Bajakah Tampala) was collected from the forests around Palangkaraya in Central Kalimantan. Polyvinyl alcohol (PVA, Mw 89,000–98,000 g/mol, 99% hydrolysed) was purchased from Sigma-Aldrich Pte Ltd in Singapore. 96% methanol was provided by Andeska Laboratory in Padang, Indonesia. Distilled water was provided by the Biota Sumatera Laboratory at the Faculty of Pharmacy, Andalas University.

2.2 Preparation of Phenolic Extract (PE)

After drying the fresh roots of Spatholobus littoralis Hassk for 72 hours and cutting them into 1 cm cubes, the next step was taken. The pieces were mixed in a dry state using a Philips blender. Next, 400 g of Spatholobus littoralis Hassk powder was soaked in 1,600 ml of methanol for 48 hours, after which it was filtered using filter paper. The liquid extract of Spatholobus littoralis Hassk (PE) was obtained by concentrating the methanol extract using a rotary evaporator.

2.3 Preparation Pure PVA Film

A total of 10 g of polyvinyl alcohol (PVA) was dissolved in 100 mL of distilled water. The mixture was then heated using a magnetic stirrer (Scilogex MS-H280-Pro) at a temperature of 80 °C with a stirring speed of 500 rpm for 2 hours until complete gelatinization was achieved. The resulting gel solution was then subjected to ultrasonication using a 1200 W SJIA sonicator probe at 360 W for five minutes, to improve homogeneity and remove air bubbles. After ultrasonication, the solution was poured into Petri dishes and dried in a vacuum oven at 50 °C for 20 hours, until a pure PVA film formed [24].

2.4 Preparation of PVA/PE (PPE) Biocomposite Film

Phenolic extract from Spatholobus littoralis (PE) was mixed into a polyvinyl alcohol (PVA) gel at concentrations of 0%, 1.25%, 2.5% and 5% of the gel's total weight. The resulting films were labelled PPE0, PPE1.25, PPE2.5 and PPE5. Each PE concentration was initially dissolved in 30 ml of technical methanol using a magnetic stirrer at 200 rpm for 30 minutes at room temperature to obtain a homogeneous dispersion [21]. The solution was then centrifuged at 2,000 rpm for 10 minutes and the resulting supernatant was filtered to remove any insoluble particles or solid residues. Meanwhile, 10 g of pure PVA was dissolved in 100 ml of distilled water, stirred at 80 °C for two hours at 500 rpm, and stirred until a uniform gel solution formed. The PE supernatant produced by filtration was then gradually added to the PVA gel while stirring continuously at 70 °C for two hours. This heating process ensured optimal mixing and facilitated the evaporation of methanol from the system. The resulting biocomposite gel was ultrasonicated for 5 minutes at 600 W using a probe sonicator (SJIA, 1200 W) to improve the homogeneity of the dispersion and remove air bubbles. The final gel mixture was poured into glass Petri dishes and dried in an oven at 50 °C for 20 hours to form a solid PVA/PE film. All resulting films were stored in a desiccator at 50% relative humidity prior to further characterisation.

2.5 Phytochemical and Antioxidant testing

Phytochemical tests were conducted to identify the presence of major bioactive compounds in the plant extracts. The qualitative analysis of these compound groups was performed using several standard methods: the magnesium chloride reduction test for flavonoid detection; the ferric chloride test for identifying phenolic compounds; the Liebermann–Burchard test for steroids; the

foam formation test for saponins; and the Mayer and Wagner tests for detecting alkaloids. In addition to qualitative analysis, total phenolic content was determined quantitatively using the Folin–Ciocalteu method with gallic acid as the standard compound and total flavonoid content was analysed using the aluminium chloride ($AlCl_3$) colorimetry method with quercetin as the standard compound. All absorbance measurements were performed using an Agilent Cary 8454 UV–Vis spectrophotometer [25,26]. Furthermore, the antioxidant activity of PPE films was evaluated using the DPPH free radical scavenging method at a concentration of 0.2 mM to assess their ability to capture free radicals.

2.6 UV Blocking Test

The transparency and light transmission properties of the film were tested using a Shimadzu UV-1800 UV–Vis spectrophotometer in the wavelength range of 200–800 nm, in accordance with the ASTM D1003-00 standard (Standard Test Method for Haze and Luminous Transmittance of Transparent Plastics). Prior to testing, PPE film samples were cut into rectangles measuring 10 × 25 mm. Each sample was analysed to determine its ultraviolet and visible light transmission capabilities, and all measurements were repeated three times to ensure the reliability and consistency of the obtained data.

2.7 Antibacterial Test

Antibacterial activity testing was performed using the disk diffusion method, with nutrient agar (NA) serving as the test medium. The test bacteria (*Staphylococcus aureus* ATCC 29213 and *Escherichia coli* ATCC 25922) were first revitalised by incubating them in an agar medium at 37 °C for 18 hours. Next, a bacterial suspension was prepared in a physiological NaCl solution to achieve a turbidity equivalent to the 0.5 McFarland standard. Then, 100 µL of the bacterial suspension was inoculated onto the surface of the NA medium and spread evenly. PPE film samples containing varying concentrations of phenolic extract (0, 1.25, 2.5 and 5wt%) were placed on the inoculated medium. All tests were conducted in triplicate to ensure the reliability of the results. The test medium was then incubated at 37 °C for 18 hours [27]. This method is based on the principle that the active compounds in the film diffuse into the solid medium containing the test bacteria. The formation of a clear inhibition zone around the film sample indicates antibacterial activity, characterised by the inhibition of microbial growth [28].

3. Results and Discussion

3.1 PE characteristics

The results of phytochemical analysis of Spatholobus littoralis phenolic extract (PE) showed the presence of various potentially bioactive secondary metabolites, including phenolic compounds such as flavonoids and phenols, as well as alkaloids, terpenoids, steroids, and saponins,

as summarized in Table 1. The presence of these diverse compounds indicates that PE extract has a complex phytochemical composition and has the potential to provide broad biological activity. These compounds are known to play an important role in the natural defense mechanisms of plants and are often associated with antioxidant and antimicrobial activities, making them relevant for application in the development of functional materials, including biopolymer-based pharmaceutical packaging.

Table 1. Bioactive Compounds of PE

Sample	Flavonoid	Phenol	Alkoloid	Terpenoid	Steroid	Saponin
A	+	+	+	+	+	+
B	+	+	+	+	+	+

Phenolic compounds, which are generally classified as polyphenols, are characterized by an aromatic ring structure containing one or more free hydroxyl groups (–OH) or their derivatives, such as esters, ethers, and glycosides [29,30]. This chemical structure allows phenolic compounds to interact effectively with the cellular components of microorganisms. The mechanism of their antibacterial activity involves disruption of the bacterial cell wall and membrane through changes in membrane permeability and denaturation of intracellular proteins. These interactions can result in disruption of cytoplasmic function, inhibition of energy metabolism, damage to genetic material, and inhibition of nucleic acid synthesis, which ultimately leads to inhibition of bacterial cell growth or death [31,32].

3.2 UV Protection

PVA films modified with phenolic extract from Spatholobus littoralis (PE) exhibited increased UV protection as the extract concentration increased. UV transmission test results showed that unmodified films (PPE0) still allowed relatively high amounts of UV radiation to pass through. By contrast, films containing the highest concentration of phenolic extract (PPE5) were able to block almost all UV radiation in the 200–400 nm wavelength range, indicating very high UV protection efficiency (Fig. 1). This increase in ability correlates directly with the concentration of phenolic compounds in the film matrix, which act as UV radiation-absorbing agents.

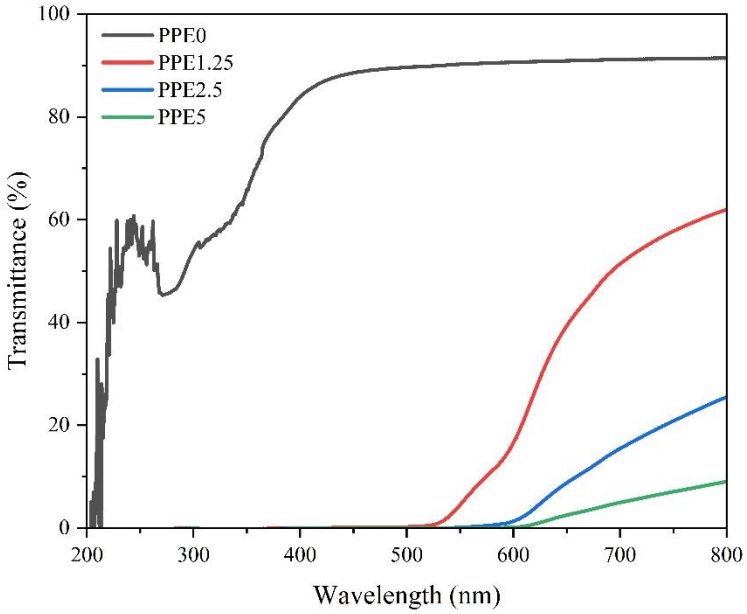


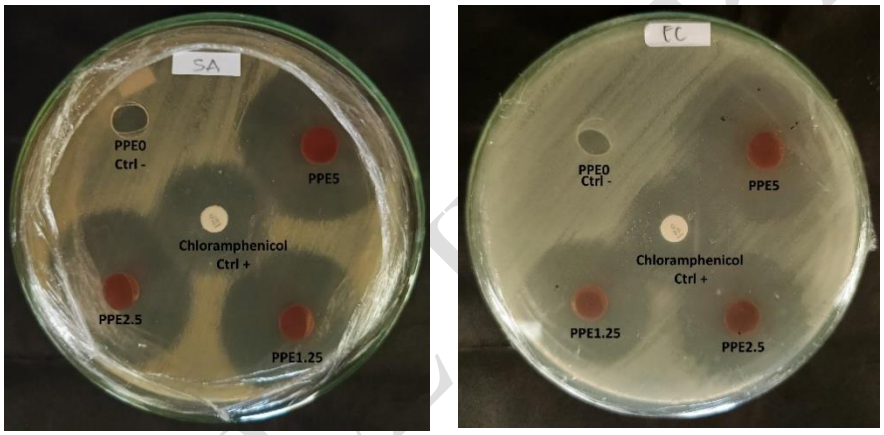
Fig. 1. UV-Blocking PPE Films

Fig. 2. Photograph of PPE Films

The decrease in film transparency observed with increasing phenolic extract concentration (Fig. 2) suggests that the bioactive compounds in the extract play an active role in UV light absorption. Although reduced transparency can affect the optical properties of the film, this phenomenon is beneficial in the context of pharmaceutical packaging as it protects the product from degradation caused by UV exposure. Phenolic compounds, particularly flavonoids and phenols, have aromatic structures that effectively absorb ultraviolet radiation energy, thus significantly improving the film's protective properties [18,33–35]. These findings align with previous reports stating that integrating natural bioactive compounds into the polymer film matrix increases UV protection and provides additional functions, such as antimicrobial activity. Therefore, PVA films enriched with phenolic extracts of S. littoralis Hask show great promise as environmentally friendly, multifunctional pharmaceutical packaging materials [16,23].

3.3 Antimicrobial and Antioxidant activity

PVA films modified with Spatholobus littoralis phenolic extracts exhibited excellent antibacterial activity against both Gram-positive and Gram-negative bacteria. The disk diffusion test revealed that increasing the phenolic extract concentration significantly enhanced bacterial growth inhibition. The film with the highest extract concentration (PPE5) produced the largest zone of inhibition: 39.1 mm against Staphylococcus aureus and 32.8 mm against Escherichia coli. This confirms the strong antibacterial effectiveness at a concentration of 5% (see Table 2). By contrast, pure PVA film without added extract (PPE0) exhibited no significant antibacterial activity, as evidenced by the absence of inhibition zones around the sample (Fig. 3). Films containing lower extract concentrations (PPE1.25 and PPE2.5) exhibited antibacterial activity, albeit with smaller inhibition zones. This indicates a direct relationship between phenolic compound concentration and bacterial inhibition effectiveness.



S. aureus *E. coli*

Fig. 3. Antibacterial performance PPE Films

The difference in the level of inhibition observed between S. aureus and E. coli can be attributed to the difference in the structure of their cell walls. S. aureus is a Gram-positive bacterium with a relatively thick peptidoglycan layer but no outer membrane, making it more susceptible to penetration by phenolic compounds. In contrast, E. coli is a Gram-negative bacterium with an outer layer containing lipopolysaccharides that can act as an additional barrier to the diffusion of bioactive compounds. It is thought that the antibacterial mechanism of S. littoralis extract involves interaction between the active compounds and the bacterial cell membrane. This results in disruption to the integrity of the cell structure, increased membrane permeability and denaturation of important proteins and enzymes involved in cellular metabolism. Ultimately, this leads to inhibited growth or bacterial cell death [36].

In addition to its antibacterial activity, the modified PVA film exhibits significant antioxidant activity, as demonstrated by testing using the DPPH method. The film's ability to capture free radicals increases with higher concentrations of phenolic extracts, highlighting the

crucial role of phenolic compounds as electron or hydrogen atom donors [37,38]. This antioxidant activity provides additional benefits, such as protecting the film and packaged pharmaceutical products from oxidative degradation and increasing the physical and chemical stability of the film during storage [10]. The combination of antibacterial and antioxidant properties confirms the PE as natural bioactive agents in the development of PVA films. Offering multifunctional protection against microbial contamination, oxidative stress and UV radiation exposure, this modified PVA film is a highly promising candidate for safe, sustainable and environmentally friendly pharmaceutical packaging applications.

Table 2. Antimicrobial and antioxidant activity of PPE

Sample	Inhibition zone diameter (mm) against microorganisms		IC_{50} (ppm)
	EC	SA	
PPE0	N/D	N/D	N/D
PPE1.25	29.51±0.8	31.12±1.6	5390.04±20.80
PPE2.5	31.33±0.9	36.67±1.4	716.09±0.76
PPE5	32.77±0.4	39.10±0.9	219.73±0.00
Ctrl +	23.63	25.69	N/D

4. Conclusions

Based on the results of this study, polyvinyl alcohol (PVA) films modified with phenolic extracts from Spatholobus littoralis Hask show strong potential as environmentally friendly active pharmaceutical packaging materials. Among the investigated formulations, the incorporation of 5 wt% phenolic extract was identified as the optimal concentration, providing the best overall performance. At this level, the modified PVA film exhibited nearly complete ultraviolet radiation blocking in the 200–400 nm wavelength range, effectively protecting active pharmaceutical compounds from photodegradation.

In addition, the film containing 5 wt% phenolic extract demonstrated the highest antibacterial activity against Staphylococcus aureus and Escherichia coli, along with enhanced antioxidant activity indicated by increased free radical scavenging ability. The combination of UV protection, antibacterial efficacy, and antioxidant properties confirms that PVA films enriched with S. littoralis phenolic extracts at an optimal concentration of 5 wt% offer an effective dual protection system. These findings highlight their potential application as a safer, sustainable, and efficient pharmaceutical packaging solution.

Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Kadriadi: Writing – original draft, Visualization, Software, Investigation. **Hairul Abral**: Supervision, Resources, Methodology, Funding acquisition, Conceptualization. **Melbi Mahardika**: Supervision, Methodology, Resources, Writing – review & editing. **Ilhamdi**: Supervision. **Akmal**: Investigation. **Dian Handayani**: Resources, Data curation. **Yulianis**: Investigation. **Mohamad Haafiz Mohamad Kassim**: Validation. **Jeri Ariksa**: Investigation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

The authors acknowledge the facilities, scientific and technical support from Nanoscience and Technology Laboratory, Andalas University. iLaB (Integrated Laboratory of Bioproducts), National Research and Innovation Agency.

References

[1] Alonso-Lopez O, Lopez-Ibanez S, Beiras R. Assessment of Toxicity and Biodegradability of Poly (vinyl alcohol) -Based Materials in Marine Water. Polymers (Basel) 2021;13:1–9.

[2] Agarwal S. Biodegradable Polymers: Present Opportunities and Challenges in Providing a Microplastic-Free Environment. Macromol Chem Phys 2020;221. https://doi.org/10.1002/macp.202000017.

[3] Cho Y, Withana PA, Rhee JH, Lim ST, Lim JY, Park SW, et al. Achieving the sustainable waste management of medical plastic packaging using a life cycle assessment approach. Heliyon 2024;10:e38185. https://doi.org/10.1016/j.heliyon.2024.e38185.

[4] Geyer R, Jambeck JR, Law KL. Production, use, and fate of all plastics ever made. Sci Adv 2025;3:e1700782. https://doi.org/10.1126/sciadv.1700782.

[5] Abral H, Kadriadi, Mahardika M, Handayani D, Sugiarti E, Muslimin AN. Characterization of disintegrated bacterial cellulose nanofibers/PVA bionanocomposites prepared via ultrasonication. Int J Biol Macromol 2019;135:591–9. https://doi.org/10.1016/j.ijbiomac.2019.05.178.

[6] Abral H, Atmajaya A, Mahardika M, Hafizulhaq F, Kadriadi, Handayani D, et al. Effect of ultrasonication duration of polyvinyl alcohol (PVA) gel on characterizations of PVA film. J Mater Res Technol 2020;9:2477–86. https://doi.org/10.1016/j.jmrt.2019.12.078.

[7] Aslam M, Kalyar MA, Raza ZA. Polyvinyl alcohol: A review of research status and use of polyvinyl alcohol based nanocomposites. Polym Eng Sci 2018;58:2119–32. https://doi.org/10.1002/pen.24855.

[8] da Cruz JA, da Silva AB, Ramin BBS, Souza PR, Popat KC, Zola RS, et al. Poly(vinyl alcohol)/cationic tannin blend films with antioxidant and antimicrobial activities. Mater Sci Eng C 2020;107:110357. https://doi.org/10.1016/j.msec.2019.110357.

[9] Chaudhary BU, Lingayat S, Banarjee AN, Kale RD. Preparation and Characterization of Antioxidant, Antimicrobial, and UV-Light Protection Film Based on Poly(vinyl alcohol) and Garlic Peel Extract. Waste and Biomass Valorization 2022;13:4717–34. https://doi.org/10.1007/s12649-022-01804-y.

[10] Gore AH, Prajapat AL. Biopolymer Nanocomposites for Sustainable UV Protective

Packaging. Front Mater 2022;9:855727. https://doi.org/10.3389/fmats.2022.855727.
[11] Kuchaiyaphum P, Chotichayapong C, Kajsanthia K, Saengsuwan N. Carboxymethyl cellulose/poly (vinyl alcohol) based active film incorporated with tamarind seed coat waste extract for food packaging application. Int J Biol Macromol 2024;255:128203. https://doi.org/10.1016/j.ijbiomac.2023.128203.
[12] Silva ID de L, Moraes Filho LEPT de, Caetano VF, Andrade MF de, Hallwass F, Brito AMSS, et al. Development of antioxidant active PVA films with plant extract of Caesalpinia ferrea Martius. LWT 2021;144:111215. https://doi.org/10.1016/j.lwt.2021.111215.
[13] Quideau S, Deffieux D, Douat-Casassus C, Pouységu L. Plant polyphenols: Chemical properties, biological activities, and synthesis. Angew Chemie - Int Ed 2011;50:586–621. https://doi.org/10.1002/anie.201000044.
[14] He X, Luzi F, Hao X, Yang W, Torre L, Xiao Z, et al. Thermal, antioxidant and swelling behaviour of transparent polyvinyl (alcohol) films in presence of hydrophobic citric acid-modified lignin nanoparticles. Int J Biol Macromol 2019;127:665–76. https://doi.org/10.1016/j.ijbiomac.2019.01.202.
[15] Qin J, Huang X, Xu Q, Jin L. Active polyvinyl alcohol films with enhanced strength, antioxidant and antibacterial properties by incorporating nanocellulose and tannin. Int J Biol Macromol 2024;283:137873. https://doi.org/10.1016/j.ijbiomac.2024.137873.
[16] Setyowati E, Irzani EF, Mochtar Luthfi CF, Hamzah H. Tracing the Antibacterial, Antifungal and Anti-Biofilm Activities of Root Extract Bajakah Tampala (Spatholobus Littoralis Hassk). J Farm Sains Dan Prakt 2024;10:32–41. https://doi.org/10.31603/pharmacy.v10i1.8804.
[17] Jesumani V, Du H, Pei P, Aslam M, Huang N. Comparative study on skin protection activity of polyphenol-rich extract and polysaccharide-rich extract from Sargassum vachellianum. PLoS One 2020;15:e0227308. https://doi.org/10.1371/journal.pone.0227308.
[18] Abral H, Ikhsan M, Rahmadiawan D, Handayani D, Sandrawati N, Sugiarti E, et al. Anti-UV, antibacterial, strong, and high thermal resistant polyvinyl alcohol/Uncaria gambir extract biocomposite film. J Mater Res Technol 2022;17:2193–202. https://doi.org/10.1016/j.jmrt.2022.01.120.
[19] Ismayati M, Fatah NAN, Ernawati EE, Juliandri, Kusumaningrum WB, Lubis MAR, et al. Antioxidant and UV-blocking activity of PVA/tannin-based bioplastics in food packaging application. Int J Biol Macromol 2024;257:128332. https://doi.org/10.1016/j.ijbiomac.2023.128332.
[20] Lan W, Zhang R, Ahmed S, Qin W, Liu Y. Effects of various antimicrobial polyvinyl alcohol/tea polyphenol composite films on the shelf life of packaged strawberries. Lwt 2019;113:108297. https://doi.org/10.1016/j.lwt.2019.108297.
[21] Rahmadiawan D, Akmal, Abral H, Azka MA, Sapuan SM, Kadriadi, et al. Solvent-selective extraction of Syzygium polyanthum bioactives for tailored polyvinyl alcohol composites: A lignocellulose-derived approach toward biorefinery-based functional materials. Biomass and Bioenergy 2026;204:108467. https://doi.org/10.1016/j.biombioe.2025.108467.
[22] Kadriadi, Rahmadiawan D, Abral H, Ilhamdi, Ivan M, Akmal, et al. A novel active packaging film based on polyvinyl alcohol/bajakah tampala (Spatholobus littoralis hassk) extract: Enhancing mechanical, UV protection, thermal stability, antimicrobial, and barrier properties. Food Biosci 2025;68:106500. https://doi.org/10.1016/j.fbio.2025.106500.
[23] Hamzah H, Pratiwi SUT, Jabbar A, Nandini E. Efficacy of Bajakah Tampala Ethanol Extract, a Typical Plant of Kalimantan Island (Borneo), Against Candida Albicans Biofilm. Eur Chem Bull 2022;11:59–63. https://doi.org/10.31838/ecb/2022.11.05.009.
[24] Abral H, Atmajaya A, Mahardika M, Hafizulhaq F, Kadriadi, Handayani D, et al. Effect of ultrasonication duration of polyvinyl alcohol (PVA) gel on characterizations of PVA film. J Mater Res Technol 2020;9:2477–86. https://doi.org/10.1016/j.jmrt.2019.12.078.
[25] Sameena VP, Thoppil JE. Assessment of phytometabolite distribution, in vitro antioxidant and anti-inflammatory potential of novel plant, Euphorbia deccanensis—endemic to South

India. Vegetos 2024;37:1513–25. https://doi.org/10.1007/s42535-023-00700-7.
[26] Woźniak M, Sip A, Mrówczyńska L, Broniarczyk J, Waśkiewicz A, Ratajczak I. Biological activity and chemical composition of propolis from various regions of Poland. Molecules 2022;28:141.
[27] Hudzicki J. Kirby-Bauer Disk Diffusion Susceptibility Test Protocol Author Information. Am Soc Microbiol 2012:1–13.
[28] Balouiri M, Sadiki M, Ibnsouda SK. Methods for in vitro evaluating antimicrobial activity : A review . J Pharm Anal 2016;6:71–9. https://doi.org/10.1016/j.jpha.2015.11.005.
[29] J.B. Harborne And PMD. Methods in Plant Biochemistry. 1989.
[30] Koopmann AK, Schuster C, Torres-Rodríguez J, Kain S, Pertl-Obermeyer H, Petutschnigg A, et al. Tannin-Based Hybrid Materials and Their Applications: A Review. Molecules 2020;25. https://doi.org/10.3390/molecules25214910.
[31] Lobiuc A, Pavăl N-E, Mangalagiu II, Gheorghiță R, Teliban G-C, Amăriucăi-Mantu D, et al. Future Antimicrobials: Natural and Functionalized Phenolics. Molecules 2023;28. https://doi.org/10.3390/molecules28031114.
[32] Dirar AI, Alsaadi DHM, Wada M, Mohamed MA, Watanabe T, Devkota HP. Effects of extraction solvents on total phenolic and flavonoid contents and biological activities of extracts from Sudanese medicinal plants. South African J Bot 2019;120:261–7. https://doi.org/10.1016/j.sajb.2018.07.003.
[33] Ismayati M, Fatah NAN, Ernawati EE, Juliandri, Kusumaningrum WB, Lubis MAR, et al. Antioxidant and UV-blocking activity of PVA/tannin-based bioplastics in food packaging application. Int J Biol Macromol 2024;257:128332. https://doi.org/10.1016/j.ijbiomac.2023.128332.
[34] Liu Y, Wang S, Lan W, Qin W. Development of ultrasound treated polyvinyl alcohol / tea polyphenol composite films and their. Ultrason - Sonochemistry 2018. https://doi.org/10.1016/j.ultsonch.2018.07.043.
[35] Zhang S, Zhang X, Wan X, Zhang H, Tian J. Fabrication of biodegradable films with UV-blocking and high-strength properties from spent coffee grounds. Carbohydr Polym 2023;321:121290. https://doi.org/10.1016/j.carbpol.2023.121290.
[36] Eelager MP, Masti SP, Chougale RB, Hiremani VD, Narasgoudar SS, Dalbanjan NP, et al. Evaluation of mechanical, antimicrobial, and antioxidant properties of vanillic acid induced chitosan/poly (vinyl alcohol) active films to prolong the shelf life of green chilli. Int J Biol Macromol 2023;232:123499. https://doi.org/10.1016/j.ijbiomac.2023.123499.
[37] Yildirim S, Röcker B, Pettersen MK, Nilsen-Nygaard J, Ayhan Z, Rutkaite R, et al. Active Packaging Applications for Food. Compr Rev Food Sci Food Saf 2018;17:165–99. https://doi.org/10.1111/1541-4337.12322.
[38] Soleimanzadeh A, Mizani S, Mirzaei G, Bavarsad ET, Farhoodi M, Esfandiari Z, et al. Recent advances in characterizing the physical and functional properties of active packaging films containing pomegranate peel. Food Chem X 2024;22:101416. https://doi.org/10.1016/j.fochx.2024.101416.