Progress in Organic Coatings xxx (xxxx) 109685

Contents lists available at ScienceDirect

Progress in Organic Coatings

journal homepage: www.elsevier.com/locate/porgcoat

Spray-coated polylactic acid/polyhydroxyalkanoate biodegradable bioplastic films on paper: A sustainable strategy for enhancing barrier and mechanical properties

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ARTICLE INFO

Keywords:
Polyhydroxyalkanoate (PHA)
Polylactic acid (PLA)
Bioplastics
Spray coating
Coated paper

ABSTRACT

This study proposes a sustainable alternative to conventional plastic coatings in packaging by developing a biodegradable coating system based on polylactic acid (PLA) and polyhydroxyalkanoate (PHA). A novel spray coating technique followed by hot pressing was used to apply PLA/PHA blends onto kraft pulp paper. This approach aimed to enhance mechanical strength, barrier properties, and water resistance while maintaining compostability. The coating behavior was strongly influenced by the PLA to PHA ratio. PLA formed a dense surface layer that effectively sealed pores, while PHA penetrated more deeply into the fibrous matrix, filling internal voids. These complementary roles contributed differently to the mechanical and barrier properties. In particular, the 50:50 PLA/PHA blend showed the most balanced results, achieving the lowest oxygen transmission rate and improved tensile strength. The thermogravimetric analysis further confirmed enhanced thermal stability in all coated samples compared to uncoated paper, with the degradation temperature profile shifting depending on the polymer composition. However, coatings with excessive PHA content showed surface irregularities and reduced barrier performance due to poor film formation. Overall, this work demonstrates that compositional tuning of PLA and PHA enables multifunctional coatings with improved mechanical, thermal, and barrier properties. The proposed spray-based method offers a scalable, eco-friendly solution for high-performance biodegradable packaging.

1. Introduction

Plastics are made of a range of semisynthetic or synthetic petrochemical compounds and are widely used in applications such as optoelectronic devices, flexible substrates, and packaging [1,2]. However, due to inadequate waste management, low recycling rate, and their non-biodegradable nature, plastic waste poses a major threat to the environment and human health [3]. Therefore, there is a critical need to develop eco-friendly, biodegradable, and biocompatible alternatives with desirable properties to replace synthetic plastic and contribute to more sustainable packaging solutions [4].

Paper is a widely known material in terms of biodegradability, recyclability, mass production feasibility, and cost effectiveness, making it suitable for various packaging applications [5]. Although paper offers several advantages as a packaging material, its application is limited by its poor gas barrier properties and mechanical strength [6]. Due to this, it is crucial to improve the gas barrier and mechanical properties of paper for wider applications. To improve properties, paper is often coated with other packaging materials such as wax, synthetic plastics, and aluminum [7]. However, the resultant coated paper loses its recyclability and biodegradability, which could increase packaging waste generation [8]. Recently, the use of biopolymer-based coatings has received grow-

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https://doi.org/10.1016/j.porgcoat.2025.109685
Received 29 August 2025; Received in revised form 16 September 2025; Accepted 18 September 2025
0300-9440/

ing industrial interest, as these coatings offer both improved functionality and environmental sustainability [9].

Extrusion paper coating is commonly used, but this method has not been widely adopted in the packaging industry due to technical challenges such as delamination, uneven edges, pinholes, and low production efficiency [2,10,11]. Furthermore, extrusion coating is primarily designed for two-dimensional applications, typically flexible packaging [12]. However, there is a growing demand for three-dimensional rigid packaging, such as molded pulp or fiber-based bottle products [13]. As an alternative, spray coating is a versatile method extensively used in various industrial applications, including coatings, paintings, and graphic arts [14–16]. This technique involves directly spraying the coating solution onto the substrate surface, utilizing different spray generation techniques such as pressured air vaporization, airless pressure spray, and electrostatic spray among other [2,17–19].

However, spray coating on paper faces has challenges in achieving a uniform thickness across substrates with surface areas and overall cost [20]. As a result, numerous studies have focused on optimizing spray coating techniques to achieve a more uniform application and enhance manufacturing productivity [20–22].

Here, we propose a manufacturing process to apply a biopolymer blend of hydrophobic polylactic acid (PLA) and polyhydroxyalkanoate (PHA) onto kraft-pulp-based paper to enhance its mechanical, oxygen barrier properties, and surface hydrophobicity [23]. PHAs are synthesized directly through the fermentation of a carbon substrate within microorganisms [2,24]. Their promising features, including biodegradability, nontoxicity, hydrophobicity, thermos-plasticity, nonlinear optical activity, and impermeability to water and gases, make them suitable for food packaging applications [2,25].

PLA is produced from lactic acid, which is derived from renewable resources like corn or sugar beets through microbial fermentation. This is regarded as a promising packaging material due to its biocompatibility, biodegradability, good mechanical properties, moderate water resistance, high transparency, and commercial availability at a reasonable price [26].

Blending PLA with PHAs has emerged as an effective strategy to enhance biodegradable polymer performance, combining PLA's mechanical strength and processability with the flexibility and superior barrier properties of PHAs. The incorporation of PHAs such as polyhydroxybutyrate (PHB) or polyhydroxybutyrate-*co*-valerate (PHBV) significantly improves PLA's ductility, impact resistance, and elongation at break, thus addressing the inherent brittleness of PLA [27]. Additionally, PLA/PHA composites exhibit enhanced barrier properties, with oxygen permeability reduced by up to 40 % compared to pure PLA, attributed to increased crystallinity induced by PHAs [28]. Thermal properties, such as crystallization rate and thermal stability, are also positively influenced, expanding their applicability in heat-sensitive packaging applications [28]. Although PLA and PHAs tend to phase-separate, employing compatibilizers or specialized processing techniques such as melt blending, extrusion, and electrospinning can improve miscibility, leading to homogeneous composites with optimized mechanical and barrier performances [29]. Consequently, these PLA/PHA blends are promising for various sustainable packaging, biomedical, and agricultural applications due to their customizable properties and biodegradability.

The manufacturing process utilizes a novel spray coating method, which provides various technical and practical benefits over traditional extrusion coating processes, adhering to sustainability criteria while meeting the functional requirements of packaging materials. The physical properties of composite films were investigated to determine their feasibility as surface modifiers for paper.

This study aims to develop an optimized spraying process for using biodegradable PLA/PHA composites on kraft pulp-based paper, with the goal of significantly enhancing mechanical strength, oxygen barrier performance and surface hydrophobicity, thereby addressing the limitations of current sustainable paper-based packaging applications.

2. Materials and methods

2.1. Materials

Pulp for paper was obtained from Smurfit Stone Corp. (Athens, GA, USA). Polylactic acid (PLA, Mn = 155,000 g/mol) was supplied by Nature Works LLC (Blair, NE, USA). According to the technical information from the manufacturer, the PLA used in this study is a bio-based, naturally derived polymer, produced from lactic acid obtained via microbial fermentation of sugars sourced from renewable agricultural feedstocks. Polyhydroxyalkanoate (PHA, Mn = 700,000 g/mol) was obtained from CJ Biomaterials (Boston, MA, USA); this PHA is biosynthesized through microbial fermentation of plant-derived carbon substrates. Dichloromethane (DCM, Fisher Chemical Inc., Pittsburgh, PA, USA) were used as solvents.

2.2. Preparation of spray coated paper

PLA and PHA are used in the coating solution. A 2.5 wt% solution of PLA was prepared by dissolving the polymer in 200 mL of DCM with stirring for 12 h at room temperature to solubilization. Similarly, a 2.5 wt% PHA solution was prepared by dissolving PHA in 200 mL of DCM, stirring for 12 h for thorough dissolution. For the PLA/PHA blend solutions, mixtures with ratios of 25:75, 50:50, and 75:25 (PLA/PHA) were prepared. Each blend was dissolved at a concentration of 2.5 wt% in 200 mL of DCM and stirred for 12 h to achieve homogeneous mixing.

2.3. Coating method

The paper substrate was secured onto a metal plate. A uniform coating of 25 mL of PLA, PHA, and their blend solutions were applied to the paper using an air spray held at a fixed distance of 15 cm. The coated paper was initially dried in a fume hood for 30 min to allow solvent evaporation, followed by further drying in an oven set at 60 °C for 24 h to remove residual solvent. For hot pressing process, the plates of the press were heated to 170 °C. A pressure of 2400 kPa was applied for 30 s to enhance the adhesion of the coating. Subsequently, the metal plate was rapidly cooled by placing it onto a copper board immersed in liquid nitrogen for 30 s to prevent thermal degradation and preserve coating integrity. The samples, all based on paper substrates, included an uncoated control (Paper) and coated papers with PLA/PHA blend solutions at varying weight ratios of 100:0, 75:25, 50:50, 25:75, and 0:100 (*w*/w), hereafter referred to as CP100:0, CP75:25, CP50:50, CP25:75, and CP0:100, respectively. A schematic of the procedure for preparing the PLA/PHA-coated paper samples is shown in Scheme 1.

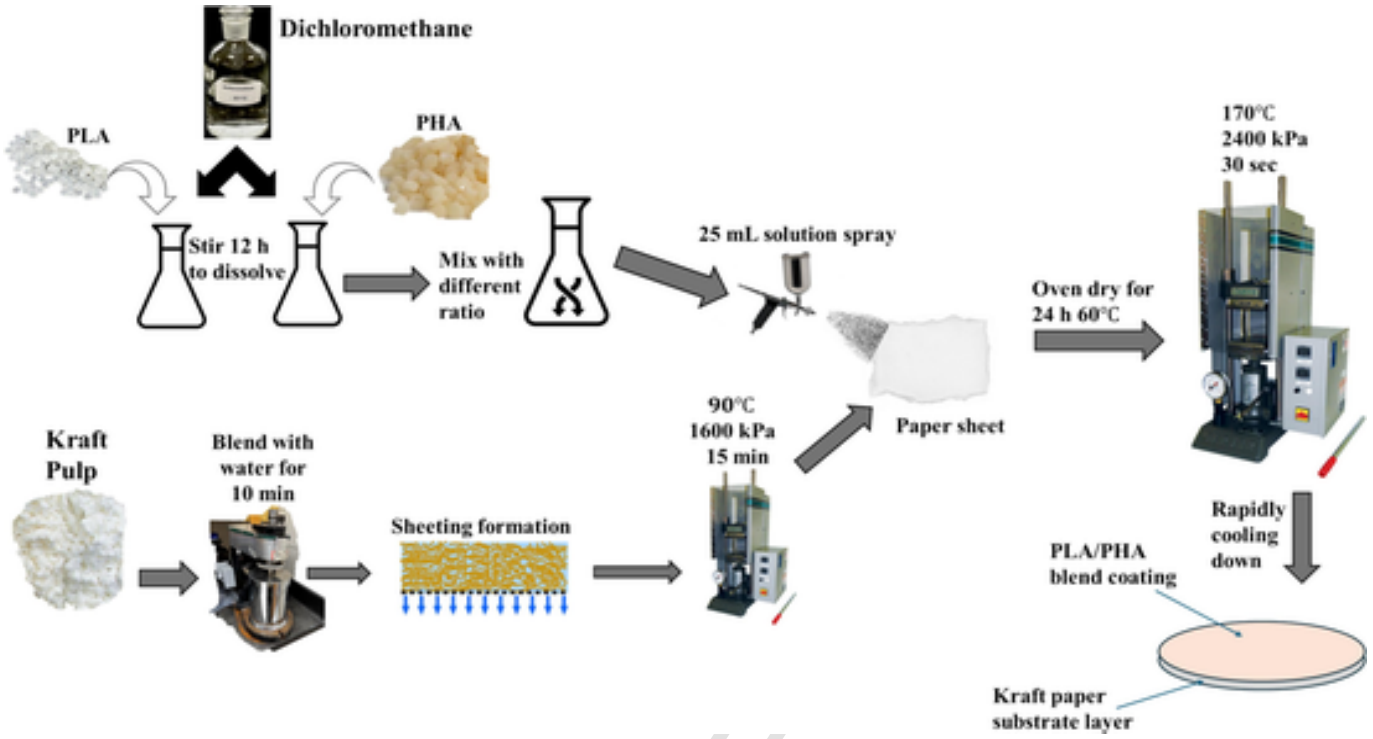
2.4. Characterization

2.4.1. Morphology

The morphologies and microstructures of uncoated and PLA/PHA-coated papers were examined by field-emission scanning electron microscopy (JEOL-IT500, JEOL Co., Ltd., Tokyo, Japan) at an accelerating voltage of 10 kV. Before the analysis, the samples were coated with a thin platinum layer using a sputter-coating device (EM-ACE600, Leica, Co., Ltd., Laughton, England). Additionally, surface roughness analyses were conducted using 3D surface profilometer (VK-X3000, Keyence, Co., Ltd., Osaka, Japan).

2.4.2. Water contact angle (WCA) analysis

The water contact angle (WCA) of the uncoated and PLA/PHA-coated papers were measured using a contact-angle goniometer (Theta Flow, Biolin Scientific Inc., Linthicum Height, MD, USA). A water droplet was carefully placed on each film. The average WCA was determined by measuring at three different locations on the sample. The



Scheme 1. Preparation procedure of PLA/PHA-coated paper substrates via airbrush deposition and thermal pressing.

droplets were observed using the θ/2 method with the droplet size approximately at the 20 scale through the eyepiece.

2.4.3. Mechanical properties

The mechanical properties of the composite films were evaluated using a universal testing machine (Instron 5944, Instron Inc., Norwood, MA, USA) with a load cell of 20 kgf at a crosshead speed of 10 mm/min according to ASTM D882 standard.

2.4.4. Thermogravimetric analysis (TGA)

Thermogravimetric analysis (TGA) of the uncoated and PLA/PHA-coated papers were performed using TGA (TGA-Q500, TA instrument, New Castle, DE, USA) in the temperature range of 25–600 °C at a heating rate of 10 °C/min under a nitrogen atmosphere.

2.4.5. Oxygen transmission rate (OTR)

The oxygen transmission rate (OTR) of uncoated and PLA/PHA-coated papers were measured using a gas transmission-rate tester (C230, Labthink Inc., Boston, MA, USA). The OTR of the specimens was determined at the temperature of 23 °C and relative humidity of 0 %, according to ASTM D3985 standard.

2.5. Statistical analysis

The experiment employed a nested design with three separate production batches, each containing five individual replicates (total sample size = 15). Data were analyzed using a one-way analysis of variance (ANOVA), considering batch variability as a random factor. Subsequent pairwise comparisons were carried out using Tukey's honest significant difference (HSD) test. All statistical evaluations were performed at a significance threshold of $\alpha = 0.05$ with IBM SPSS Statistics (version 25.0; IBM Corp., Armonk, NY, USA).

3. Results and discussion

3.1. Morphology

Fig. 1 presents SEM images of the uncoated paper and PLA/PHA coated papers. As shown in Fig. 1a, the uncoated paper sheets show a typical fibrous network structure [29]. In contrast, the coated paper without hot press treatment exhibited an uneven coating morphology (Fig. 1b). The uneven coating on the bare fibrous morphology of the paper can be attributed by the spray coating. Spray coating is suited for structures with high aspect ratios and uneven surfaces [30]. After

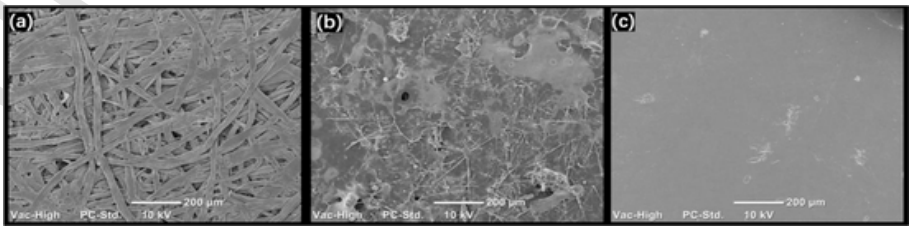


Fig. 1. SEM images at x100 magnification: (a) uncoated paper, (b) after spray coating without hot pressing, and (c) after spray coating followed by hot pressing.

the hot-press treatment, however, the coated paper surface appeared uniformly covered with the PLA/PHA blend (Fig. 1c), indicating that hot pressing significantly improved coating uniformity.

As shown in Fig. 2, the penetration of the coating into the paper sheet was strongly dependent on the concentration of PHA. As the concentration of PHA increased, the coating penetrated more deeply into the paper sheet. Previous studies have reported that PHA generally exhibits lower crystallinity and higher chain flexibility than PLA, which can enhance its flowability in solution [31]. These intrinsic properties, along with its lower thermal stability, likely contributed to the deeper penetration of PHA into the paper matrix during hot pressing, as the polymer softened more readily at the processing temperature.

Furthermore, the surface roughness of the PLA/PHA-coated papers was determined using a 3D surface profilometer, as shown in Fig. 3. The hot press treatment changed the morphology of coated papers, thereby affecting their surface roughness. The CP100:0 exhibited a surface roughness (Sz) of 39.291 μm. As the proportion of PHA in the coating increased, Sz gradually rose, reaching 106.207 μm for the CP 0:100. The observed increase in roughness is consistent with the enhanced penetration behavior of PHA-rich blends, as further supported by the SEM images [31].

This demonstrates that the ratio of PLA to PHA content significantly affects the surface roughness. According to the Lotus effect, the hydrophobicity of a surface can be enhanced by increasing its roughness, which suggests that the hydrophobicity of the coated paper surface depends on the PLA/PHA ratio in the coating solution.

3.2. WCA

The WCA was measured at both 0 s and 60 s to evaluate the initial hydrophobicity and time-dependent wettability of the PLA/PHA-coated paper samples, as shown in Fig. 4. This evaluation is particularly important for biopolymer coatings, where surface absorption and dynamic spreading behavior can significantly influence long-term water resistance [32].

At 0 s (Fig. 4a), the uncoated paper exhibited a low WCA of 39.43 ± 7.18°, indicating a hydrophilic surface [33]. Upon coating, all samples showed significantly increased WCA values. Notably, as the

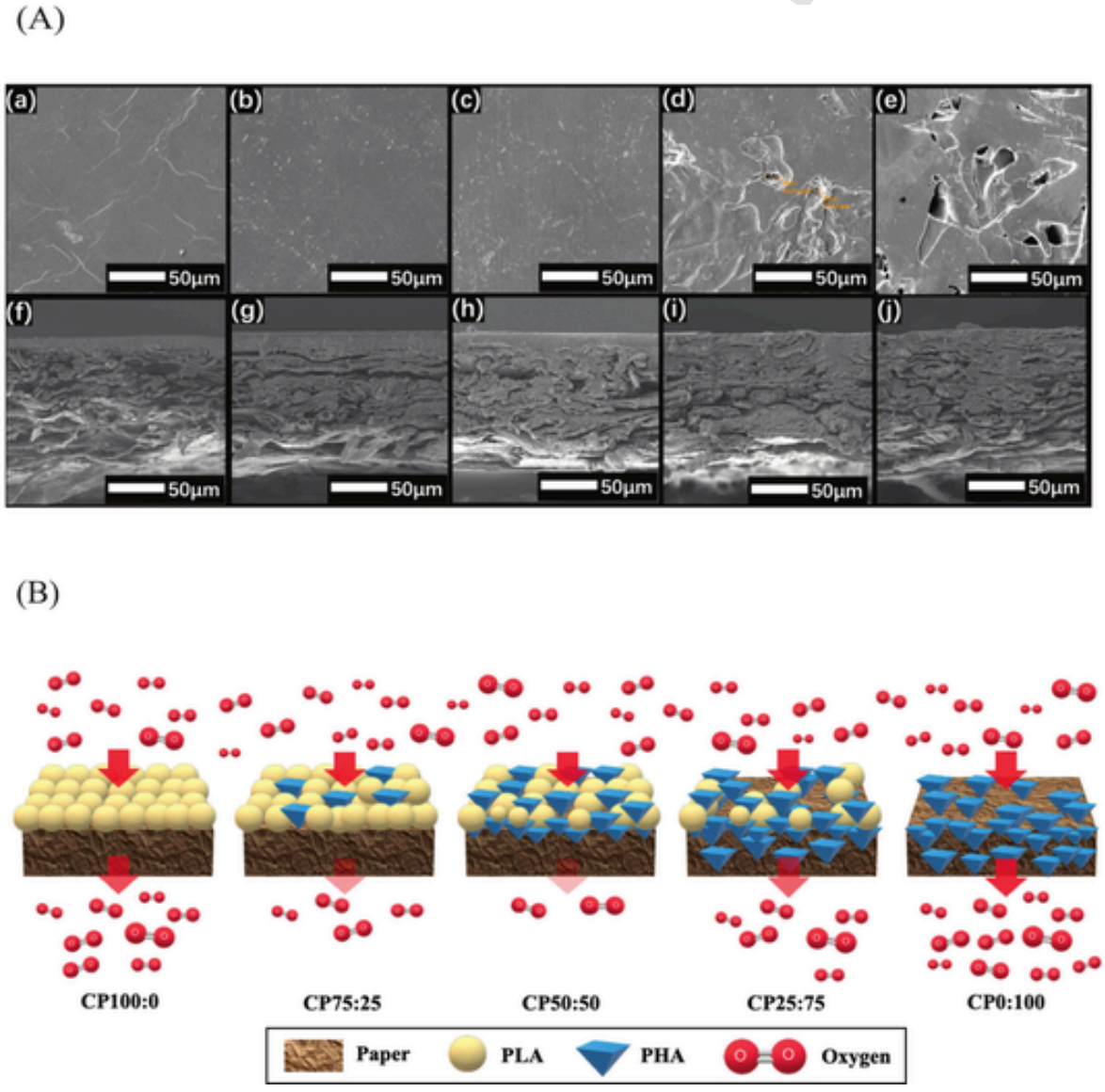


Fig. 2. (A) Surface (a–e) and cross-sectional (f-j) morphology of samples at x500 magnification and (B) the proposed relationship to oxygen barrier property (B): (a) CP100:0, (b) CP75:25, (c) CP50:50, (d) CP25:75, (e) CP0:100, (f) CP100:0, (g) CP75:25, (h) CP50:50, (i) CP25:75, and (j) CP0:100.

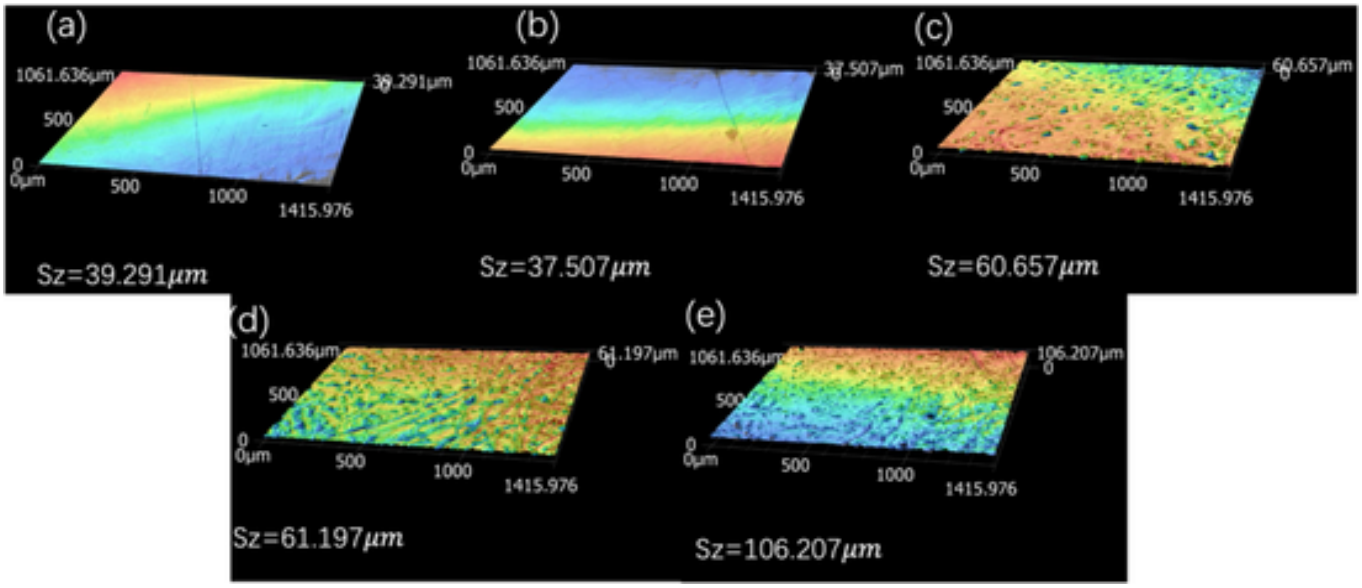


Fig. 3. (a-e) Surface roughness images of PLA/PHA coated papers: (a) CP100:0, (b) CP75:25, (c) CP50:50, (d) CP25:75, (e) CP0:100.

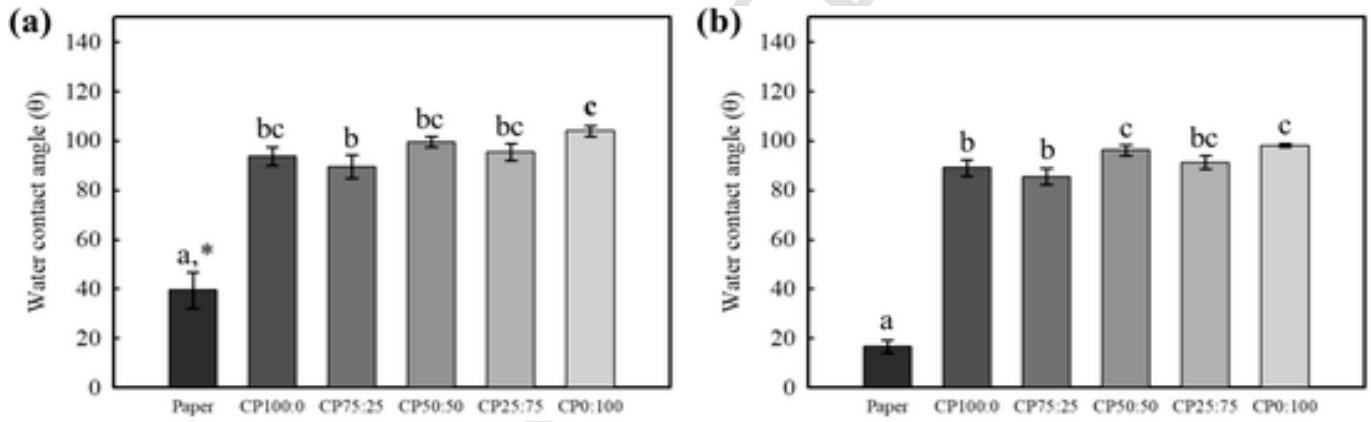


Fig. 4. Contact angle of uncoated and PLA/PHA-coated papers at (a) 0 s, (b) 60s. *Different letters indicate significant differences between groups ($p < 0.05$), as determined by Tukey's HSD test. Values are presented as mean ± standard deviation.

PHA content increased, the WCA also increased, reaching a maximum value of 103.69 ± 2.01° for CP0:100. This trend is consistent with the 3D profilometry results (Fig. 3), which demonstrated increased surface roughness with higher PHA content. According to the Lotus effect, increased roughness can decrease the solid–liquid contact area, thereby enhancing apparent hydrophobicity [34]. After 60 s (Fig. 4b), only a slight decrease in WCA was observed across all samples, indicating that the coated surfaces retained their hydrophobic character over time. The sustained contact angles suggest stable water repellency, regardless of the PLA/PHA ratio.

These findings demonstrate that increasing the PHA content enhances the surface hydrophobicity of the coated paper, primarily due to increased surface roughness and stable water repellent behavior.

3.3. Mechanical properties

The tensile strength and elongation at break of the uncoated paper and PLA/PHA-coated papers are summarized in Table 1 and illustrated in Fig. 5. All coated samples exhibited significantly higher tensile strength compared to the uncoated paper (37.96 ± 1.16 MPa), indicating that the application of biopolymer coatings effectively reinforces the mechanical integrity of the paper substrate [35].

Among the coated samples, CP0:100 showed the highest tensile strength (73.22 ± 0.65 MPa). This result is attributed to the deeper

Table 1
Mechanical properties of paper and PLA/PHA-coated papers.

Samples	Mechanical Properties		
	Thickness (μm)	Tensile stress (MPa)	Elongation (%)
Paper	$75.08 \pm 2.37^{a,*}$	37.96 ± 1.16^{a}	0.40 ± 0.03^{a}
CP100:0	97.23 ± 6.75^{b}	59.66 ± 2.44^{c}	1.00 ± 0.01^{c}
CP75:25	94.64 ± 5.45^{b}	57.21 ± 0.78^{c}	0.89 ± 0.06^{bc}
CP50:50	98.13 ± 1.89^{b}	47.96 ± 1.67^{b}	0.77 ± 0.04^{b}
CP25:75	93.77 ± 9.74^{b}	55.88 ± 1.83^{c}	0.99 ± 0.05^{c}
CP0:100	92.79 ± 6.05^{b}	73.22 ± 0.65^{d}	1.29 ± 0.08^{d}

* Different letters indicate significant differences between groups ($p < 0.05$), as determined by Tukey's HSD test. Values are presented as mean ± standard deviation.

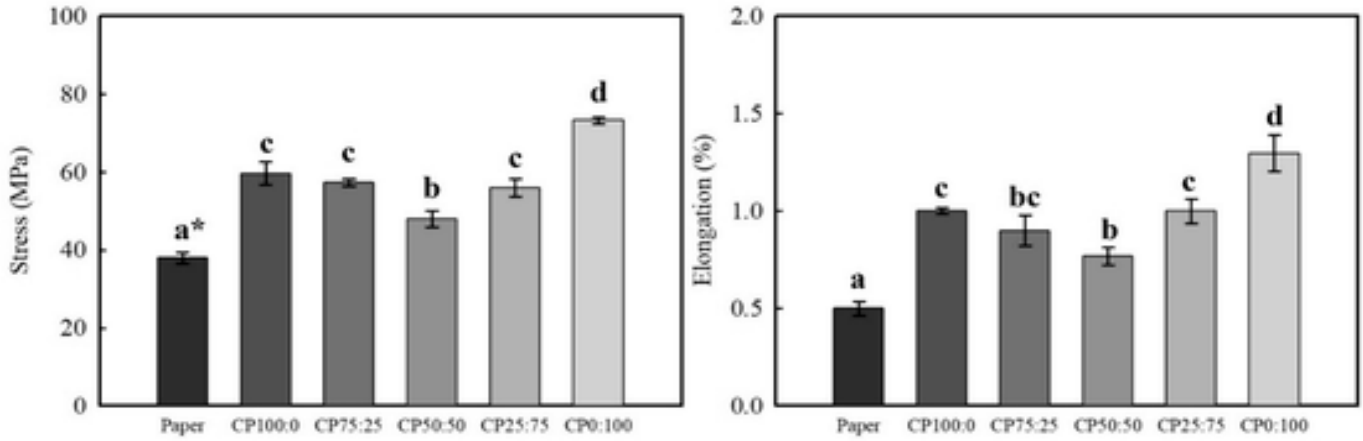


Fig. 5. Tensile stress and elongation at break of uncoated and PLA/PHA-coated paper. *Different letters indicate significant differences between groups ($p < 0.05$), as determined by Tukey's HSD test. Values are presented as mean ± standard deviation.

penetration of PHA into the fibrous structure of the paper during hot pressing, which likely allowed the polymer to fill internal voids and enhance interfacial cohesion [36]. CP100:0 also demonstrated a substantial increase in tensile strength (59.66 ± 2.44 MPa), which can be explained by strong interfacial adhesion between PLA and paper substrate [37]. PLA's relatively high modulus and compatibility with cellulose fibers promote efficient stress transfer at the interface [38].

In contrast, CP50:50 exhibited the lowest tensile strength (47.96 ± 1.67 MPa) among the coated samples. This reduction may result from phase separation or immiscibility between PLA and PHA at the 1:1 ratio, leading to a non-uniform coating morphology or weakened adhesion [39].

Elongation at break remained relatively consistent across all coated samples, ranging from 0.77 % to 1.29 %, indicating that the PLA/PHA ratio had a limited impact on the flexibility of the coated paper.

These findings highlight that the mechanical performance of coated paper is governed primarily by the adhesion at the coating–substrate interface and the extent of coating penetration into the fibrous network, both of which are strongly influenced by the PLA/PHA ratio.

3.4. Thermal properties

The thermal stability of the uncoated paper and PLA/PHA-coated papers was assessed using TGA, as shown in Fig. 6. All samples exhibited a single-step degradation process, with the major weight loss occurring in the temperature range of 250–400 °C.

The uncoated paper exhibited a sharp weight loss starting at approximately 310 °C, corresponding to the thermal decomposition of cellulose fibers [40]. In contrast, all PLA/PHA-coated samples (CP100:0 to CP0:100) showed delayed onset of decomposition, indicating improved thermal stability provided by biopolymer coatings.

Among the coated samples, CP100:0 showed a major decomposition onset near 360–380 °C, which is consistent with the typical degradation temperature of PLA, attributed to random chain scission and depolymerization [41]. In comparison, CP0:100 showed a markedly earlier decomposition onset around 260 °C to 290 °C, which reflects the lower thermal stability of PHA due to the cleavage of ester linkages in its aliphatic backbone [42].

As the proportion of PHA increased, the degradation onset temperature progressively shifted to lower values, and the thermal degradation profile became broader. This trend clearly reflects the inherently lower

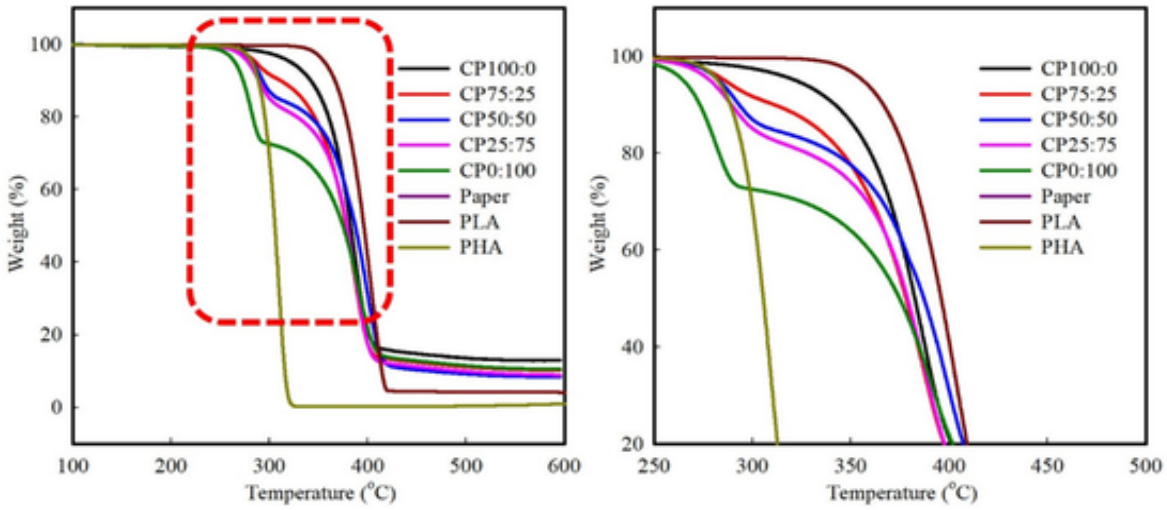


Fig. 6. TGA thermograms of uncoated paper and PLA/PHA-coated paper samples with varying blend ratios.

thermal stability of PHA compared to PLA [29]. Since the blends did not exhibit any additional decomposition steps, the thermal degradation behavior of each sample appears to be governed primarily by the individual thermal characteristics of PLA and PHA and their relative proportions in the coating. The absence of new degradation peaks further indicates that no significant chemical interactions or covalent bonding occurred between the two polymers during the coating process.

3.5. Oxygen barrier properties

The oxygen barrier properties of the PLA/PHA-coated papers were evaluated using OTR measurements, and the results are summarized in Table 2.

The CP100:0 sample exhibited a reduction in OTR (199.09 ± 68.32 cc/m^2·24h) compared to uncoated paper, indicating that PLA contributes to moderate oxygen barrier properties primarily through its uniform film-forming ability [43]. As the PHA content increased, the OTR values further decreased, reaching a minimum of 15.15 ± 1.25 cc/m^2·24h for CP50:50. This enhanced barrier performance can be attributed to the complementary roles of PLA and PHA, as supported by SEM observations. PHA coatings exhibited deeper penetration into the paper matrix, effectively filling inter-fiber voids and reducing internal diffusion pathways, while PLA formed a continuous and dense surface film that sealed surface pores [44].

However, at higher PHA content (CP25:75) the OTR sharply increased to 139.89 ± 63.66 cc/m^2·24h. SEM analysis revealed that coatings with high PHA content exhibited surface irregularities and voids, which likely served as diffusion pathways for oxygen, compromising the barrier integrity [45].

In the case of CP0:100, OTR could not be measured due to extensive surface discontinuities and poor film formation observed in SEM micrographs, suggesting that PHA alone failed to establish a continuous and effective barrier layer.

These results indicate that moderate incorporation of PHA into PLA coatings enhances oxygen barrier properties through improved pore sealing and matrix infiltration. However, excessive PHA loading leads to morphological defects that limit barrier effectiveness, underscoring the importance of optimizing the PLA/PHA ratio for functional coating performance.

It is worth noting that DCM was used as the main solvent in this study because it effectively dissolves both PLA and PHA, enabling homogeneous coatings. Nevertheless, DCM is classified as a CMR substance, which raises serious health and environmental concerns. To address these limitations, several non-CMR solvents and alternative processing methods can be considered. Ethyl acetate and ethyl lactate have been reported as effective and safer solvents for PLA, with lower toxicity and better alignment with green chemistry principles [46]. Ethyl lactate, in particular, is biodegradable and bio-derived, making it a promising candidate for sustainable coating formulations. Furthermore, recent advancements in water-based processing indicate that bio-based polymers can be formulated into coatings without relying on volatile organic solvents, thereby enhancing operator safety and reducing VOC emissions [47]. For PHA specifically, water suspension and dispersion methods have been successfully explored as functional barrier coatings on paper substrates, providing solvent-free alternatives that further enhance sustainability [48].

Table 2
Oxygen transmission rate of uncoated and PLA/PHA-coated paper samples.

Sample Composition	Thickness (μm)	Oxygen Transmission Rate (cc/(m^2·24h))	Oxygen Transmission Rate Coefficient (cc·cm/(cm^2·s·cmHg))
Paper	75.08 ±2.37^{a,*}	N/A	N/A
CP100:0	97.23 ±6.75^{b}	199.09±68.32^{b}	2.70E-11±1.00E-11^{b}
CP75:25	94.64 ±5.45^{b}	51.08±23.27^{a}	8.10E-12±4.63E-12^{ab}
CP50:50	98.13 ±1.89^{b}	15.15±1.25^{a}	1.93E-12±1.66E-13^{a}
CP25:75	93.77 ±9.74^{b}	139.89±63.66^{ab}	1.81E-11±1.13E-11^{ab}
CP0:100	92.79 ±6.05^{b}	N/A	N/A

* Different letters indicate significant differences between groups ($p < 0.05$), as determined by Tukey's HSD test. Values are presented as mean ± standard deviation.

4. Conclusion

In this study, a novel spray coating method combined with hot pressing was successfully employed to fabricate PLA/PHA-coated paper for sustainable packaging applications. By varying the PLA-to-PHA ratio, the coating formulations enabled tunable control over morphological, mechanical, thermal, and oxygen barrier properties. PLA-rich coatings provided dense surface sealing and strong interfacial adhesion, whereas PHA-rich blends penetrated more deeply into the paper matrix, enhancing cohesion but causing morphological defects at high loadings. Notably, CP50:50 achieved the most favorable balance between barrier and mechanical performance, exhibiting the lowest OTR and moderate tensile strength. In contrast, coatings with excessive PHA content showed surface voids and reduced performance, while PLA-rich samples offered higher thermal stability but less effective barrier functionality. These findings suggest that the ratio of PLA to PHA critically governs coating morphology and performance, and that optimizing this ratio is essential for achieving multifunctional biopolymer-coated paper suitable for eco-friendly packaging. The proposed method offers a scalable and sustainable alternative to conventional plastic coatings, providing a promising route toward high-performance, biodegradable packaging solutions. Although DCM was employed in this proof-of-concept study to ensure effective dissolution of both PLA and PHA, future work will focus on replacing it with safer green solvents such as ethyl acetate or ethyl lactate and on exploring water-based dispersion techniques to enhance sustainability and industrial applicability.

CRediT authorship contribution statement

Chenxi Cao: Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Kihyeon Ahn:** Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Su Jung Hong:** Writing – review & editing, Validation, Supervision, Project administration, Conceptualization. **Young-Teck Kim:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition. **Zunhuang He:** Software, Methodology. **Haibo Huang:** Writing – review & editing. **Zhiwu Wang:** Writing – review & editing, Conceptualization. **Eunhye Lee:** Writing – review & editing. **Yookyoung Shim:** Writing – review & editing.

Funding

This study was supported by United States Department of Agriculture National Institute of Food and Agriculture: Award No. 2023–79000–38973 and Award No. 2023–67017-40749. The contribution of author Dr. Su Jung Hong was financially sponsored by the BK21 FOUR program of Graduate School, Kyung Hee University (GS-1-JONON-20242323).

Declaration of competing interest

The authors do not have any conflicts of interest to declare.

Acknowledgements

PHA and its technical information which was used in this study was generously provided from CJ Biomaterials (Boston, MA, USA).

Data availability

Data will be made available on request.

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