



Thermal and Water Uptake Behavior of *Copernicia prunifera* Leaf Extract/PEG-Loaded Cellulose Acetate

Naile Angın ^{1*}

¹ Department of Forest Industry Engineering, Bursa Technical University, 16310 Bursa, Türkiye

ARTICLE INFO

Received Date: 17/09/2025
Accepted Date: 5/12/2025

Cite this paper as:

Angın, N. (2026). Thermal and Water Uptake Behavior of *Copernicia prunifera* Leaf Extract/PEG-Loaded Cellulose Acetate. *Journal of Innovative Science and Engineering*. 10(1), 131-137.

*Corresponding author: Naile Angın
E-mail:naile.angin@btu.edu.tr

Keywords:

Cellulose derivatives
Cellulose acetate
Cellulose-based functional materials
Non-wood forest products

© Copyright 2026 by
Bursa Technical University. Available
online at <http://jise.btu.edu.tr/>



The works published in Journal of Innovative Science and Engineering (JISE) are licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

ABSTRACT

Polymers derived from lignocellulosic sources have gained increasing attention in recent years due to their environmental sustainability, biocompatibility, and renewability. In this study, thermal properties and water uptake behavior of cellulose acetate loaded with PEG1500 and *Copernicia prunifera* leaf extract were investigated. A twin-screw extruder and hot press moulding was used in the manufacturing process. An ATR-FTIR analysis was performed to identify the functional groups within the structure and to assess possible chemical changes. Thermogravimetric analysis (TGA) and Differential scanning calorimetry (DSC) analyses were performed to determine the material's thermal properties. Subsequently, water uptake test was performed. The FTIR analysis results showed the characteristic peaks of the raw materials as expected, and no new functional groups were formed among the components. TGA results revealed that adding PEG1500 decreased the onset temperature of thermal degradation, whereas adding extract increased it by 20–30 °C. Similar behaviour was also observed in the DSC analysis, the glass transition temperature of composites increased by 5–10 °C with the addition of the extract. Additionally, its wax-like structure strengthened the hydrophobic character of the matrix by reducing its water uptake capacity. The water uptake rate of PEG-loaded cellulose acetate (w/w;10/90) decreased by 6% with the extract (5%) addition. The findings indicate that *Copernicia prunifera* leaf extract compensated for the negative properties of PEG1500 and was found to be suitable for use together in a cellulose acetate matrix. Using natural and biodegradable ingredients in composite systems can create an eco-friendly alternative to plastic, reducing the ecological footprint and supporting the circular economy.

1. Introduction

The current climate and industrial circumstances are driving an increasing need for environmentally friendly and sustainable materials. Cellulose is considered an environmentally friendly substitute for synthetic polymers, thanks to its widespread natural presence and cost-effectiveness (Madhushree et al., 2024). Despite its benefits, cellulose has certain disadvantages over other polymers, including poor

solubility and no thermoplastic properties. As a result, cellulose derivatives have been developed for application in specific functional domains (Oprea & Voicu, 2020). Cellulose acetate is synthesised through the esterification process using cellulosic materials (Figure 1) like cotton, wood, sugarcane, and wastepaper (Seddiqi et al., 2021). In a typical ester reaction, cellulose acetate is traditionally produced by acetylating hydroxyl groups in cellulose with acetic anhydride (Biswas et al., 2006; Khoshnevisan et al.,

2018). Various sectors widely employ cellulose acetate, including biomedical technology, filtration systems, the textile and fiber industry, alongside optical and film applications. In addition to these, the literature contains some examples of functional composite materials formed with cellulose acetate. (Wang et al., 2012) prepared biocompatible composite materials containing cellulose acetate and maleic anhydride-modified polylactic acid with the aim of improving the mechanical, thermal and biological properties of the composite and using it as a wound dressing. On the other hand, cellulose acetate is a glass-like material that is very hard and brittle. This can sometimes make it difficult to use in processes such as extrusion or film formation. A previous study reported that adding wool fibres to cellulose acetate made it suitable for filament spinning (Aluigi et al., 2008).

cellulose acetate matrix improves the morphology, permeability, flexibility of membranes (Doosti & Abedini, 2022; Kim et al., 2021). Another consideration when using PEG is its hydrophilicity. Although the PEG additive is advantageous in imparting hydrophilicity to the cellulose acetate (CA) matrix, this property can be a disadvantage in some applications. Increased hydrophilicity can negatively impact the material's efficacy, particularly in uses demanding a water barrier, like food packaging, due to increasing moisture permeability. High water uptake can lead to problems such as swelling, dissolution or reduced mechanical stability of composites. In structural biomaterials, water-induced dimensional change and structural instability are undesirable. For this reason, the PEG content and molecular weight must be carefully optimised for each application.

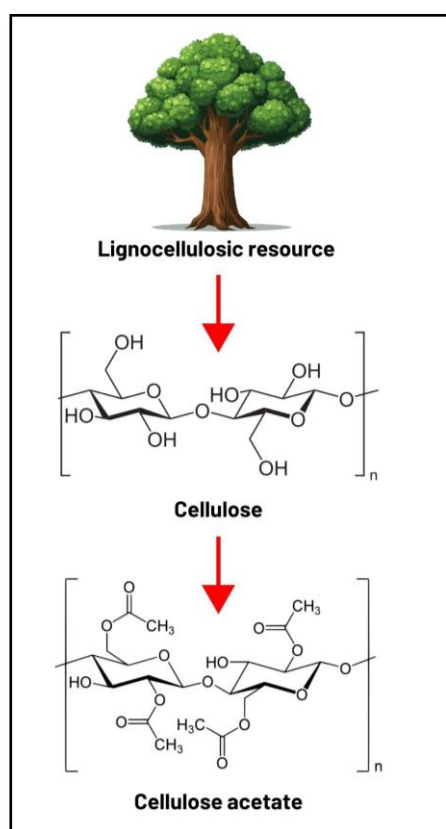


Figure 1: Resources and chemical formula of cellulose acetate.

Polyethylene glycol (PEG) is an agent that is often used as a plasticiser in polymer matrices (Jacobsen & Fritz, 1999). However, PEG manages both viscosity and ease of processing, which proves exceptionally useful for applications requiring an extrusion process. PEG and cellulose acetate are widely used together, particularly in membrane technology. Many studies in the literature have used this combination, and it has been demonstrated that incorporating PEG into the

Unlike previous studies, this study added *Copernicia prunifera* leaf extract (CPLÉ) to the mixture to improve the water uptake properties of PEG loaded-cellulose acetate. CPLÉ is a wax-like material that is often used as a coating in the automotive industry and is naturally water-repellent. Systematic evaluations of water uptake and thermal stability were conducted to determine the performance of composites obtained by loading CPLÉ into this matrix. In this context, the study aims to make a scientific contribution to the design and characterization of environmentally friendly cellulose-based material enriched with natural additives for biodegradable functional membrane and building applications.

2. Material and Methods

2.1. Material

Biograde® C 5508 branded cellulose acetate (CA) was supplied from FKUR. PEG1500 was purchased from ZAG Chemistry and CPLÉ was sourced from Dastan Chemistry.

2.2. Methods

2.2.1. Production of CPLÉ/PEG Loaded CA

Raw materials were prepared according to the mixture ratio given in Table 1. A twin-screw extruder (Gulnar Makine, Türkiye) was used in the manufacturing process. The temperature setting of the extruder was set as described in our previous study (Angın et al., 2019). The products were granulated, and the moisture was removed at the end of the extrusion process. Granulated samples were moulded via Carver branded hot-press at 190 °C and under 0.24 MPa pressure for five minutes.

Table 1: Manufacturing recipe of CPLE/PEG loaded CA

ID	CA (wt.%)	PEG (wt.%)	CPLE (wt.%)
CA	100	-	-
CAP5	95	5	-
CAP10	90	10	-
CAP5-W5	90	5	5
CAP10-W5	85	10	5

2.2.2. Fourier Transform Infrared Spectroscopy (FTIR) Analysis

ATR-FTIR measurements were performed with a Bruker Tensor branded device. FTIR spectra were recorded at wavelengths ranging from 400 to 4000 cm⁻¹. The measurements were performed at a spectral resolution of 4 cm⁻¹ with 32 scans.

2.2.3. Thermogravimetric Analysis (TGA)

Hitachi STA7200 brand thermal analyzer was used for TGA measurements. The analysis was performed by heating the samples from 30 °C to 800 °C at a rate of 10 °C/min under inert atmosphere (nitrogen) flowing at 200 mL/min. All samples, weighing between 8 and 10 mg, were placed in open ceramic pans.

2.2.4. Differential Scanning Calorimetry (DSC)

Differential Scanning Calorimetry (DSC) analyses were conducted using a TA Instruments (USA) calorimeter under a nitrogen atmosphere at a flow rate of 100 mL/min, in accordance with ASTM D3418. To determine the glass transition temperature of the materials, the temperature setting was set to increase from 30 °C to 200 °C with 10 °C/min heating rate.

2.2.5. Water Uptake Ratio

The oven-dried samples (50mm x 50mm x 5 mm) were left in distilled water for 3, 24, and 72 hours at room temperature for the water absorption test. Water uptake ratios were calculated according to Equation 1.

$$\text{Water Uptake (\%)} = [(W_2 - W_1) / W_1] \times 100 \quad (1)$$

3. Results and Discussion

3.1. FTIR Analysis

The FTIR spectra of materials are given Figure 2. Typically, C=O bonds are necessary in cellulose acetate. The reason for this is that a substitution reaction is expected to occur between the -OH bonds in cellulose and the acetyl groups, resulting in the

formation of C=O bonds (Tristantini & Yunan, 2018). Supporting this idea, the peak between 1730-1740 cm⁻¹ is due to C=O bonds in the chemical structure of cellulose acetate. The peak seen around 1373 cm⁻¹ consists of C-H stretching, which is a type of molecular vibration. Furthermore, the peaks at 1240 cm⁻¹ and 1100 cm⁻¹ are thought to indicate the presence of a C-O bond. The spectrum of cellulose acetate is consistent with previous findings in the literature (Arundati et al., 2024). The addition of PEG1500 to the matrix was clearly reflected in the FTIR spectrum, with the formation of peaks that were not present in cellulose acetate. Examination of the FTIR spectrum of the CAP5 sample reveals a split structure at 2920 cm⁻¹ and 2875 cm⁻¹. The presence of PEG1500 was found to cause these peaks, which were attributed to the -CH₃ and -CH₂ functional groups (Li et al., 2020). Similar behavior was observed in all groups containing PEG1500. On the other hand, the addition of the extract to the matrix produced no significant changes in the FTIR results. However, it is known that the wax-like extract contains similar aliphatic groups to those in PEG1500, with peaks in similar regions. In support of this view, a previous study reported that aliphatic peaks of the extract were observed between 2920-2849 cm⁻¹ (Zhang, 2024). Therefore, no clear difference could be observed due to the overlapping of these peaks, as expected.

3.2. TGA

TG and DTG curves of CPLE/PEG loaded cellulose acetate are given Figure 3. It was observed that the degradation temperature of neat cellulose acetate started at 263.7 °C and the maximum degradation occurred at 366.8 °C. Previous studies in the literature have also reported that the thermal degradation resulting in the rupture of acetyl groups is between 200 and 500 °C (Candido et al., 2017; Hanna et al., 1999). The onset of degradation decreased by about 20 °C with the addition of PEG1500 to the matrix because PEG1500 is thermally unstable. With the addition of 5% extract, the initial degradation temperature increased to 265.6 °C and 269.8 °C in the CAP5-W5 and CAP10-W5 samples, respectively. The movement of polymer chains could be limited to create a heat-resistant structure. This enables thermal energy to be transferred more slowly and delays degradation. Similar results have been reported previously for wax-enriched polymers (Righetti et al., 2019; Zhang et al., 2018). Residue amounts were found to be around 8 wt% in all samples. The addition of PEG and extract had no remarkable effect on residual ash.

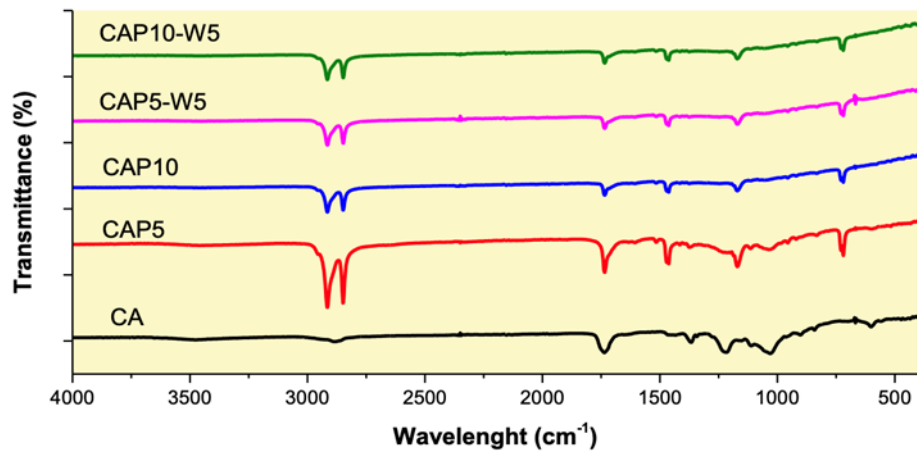


Figure 2: FTIR spectra of CPLE/PEG loaded Cellulose Acetate.

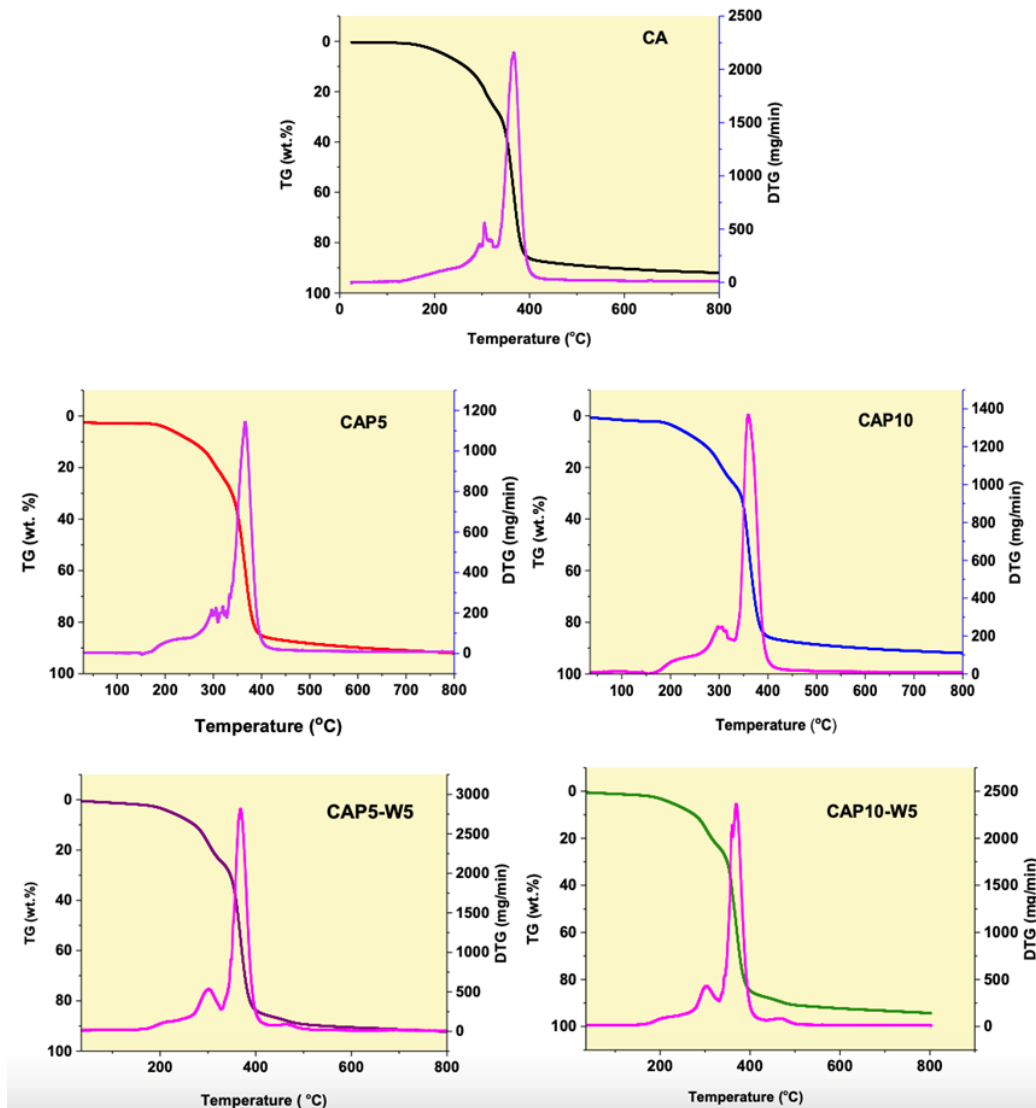


Figure 3: TG and DTG curves of CPLE/PEG loaded Cellulose Acetate.

3.3. DSC analysis

Differential Scanning Calorimetry analysis was applied to evaluate the change in the glass transition point (T_g) of the material (Figure 4). The first peak of the neat cellulose acetate sample was found to be 57.44 °C. However, the literature reports that the T_g of cellulose acetate can be quite variable, with some publications even stating that it can exceed 100 °C (Erdmann et al., 2021; Kamide & Saito, 1985). This variation is thought to be due to differences in the degree of substitution of the cellulose acetate used. In this study, the low glass transition point was attributed to the negative effect of the extrusion and hot moulding processes on the material's thermal properties (Partheniadis et al., 2020).

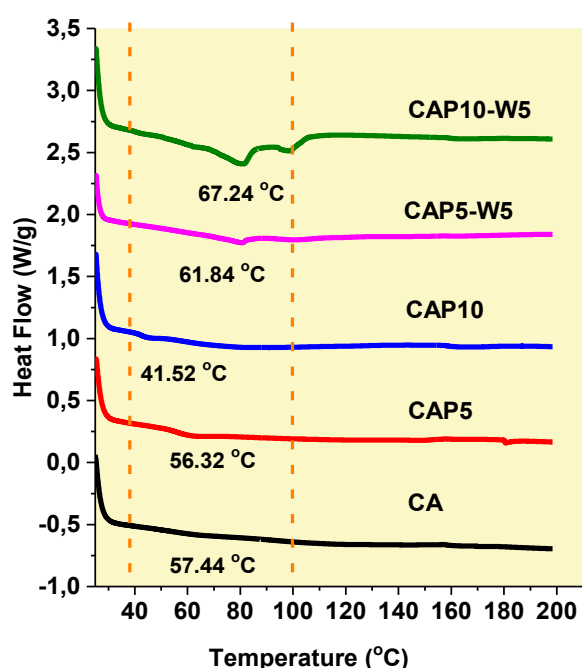


Figure 4: DSC analysis of CPLE/PEG loaded Cellulose Acetate.

When PEG1500 was incorporated into the structure, a noticeable reduction in the T_g value was observed. Specifically, the CAP10 sample, which contained 10% PEG, exhibited a glass transition temperature approximately 15 °C lower than that of neat cellulose acetate. This is due to the plasticizing effect of PEG, as frequently reported in the literature (Septevani & Bhakri, 2017). On the other hand, the addition of CPLE increased the glass transition point by up to 67 °C. Unlike PEG1500, CPLE has a relatively high melting point (82–86 °C), meaning it can act as a rigid phase, preventing movement within the polymer matrix. A reduction in the flexibility of the polymer chains, which are created by PEG, leads to a rise in T_g . Wax-like substances are known to improve the thermal properties of the polymer (Alkan et al., 2009).

3.4. Water Uptake Ratio

Figure 5 shows the water uptake ratios of the samples at the end of 3, 24 and 72 hours. Cellulose acetate is a slightly hygroscopic material, but depending on the degree of acetylation, it has fairly good resistance to water. The cellulose acetate used in this study did not absorb any water in the first 3 hours but it absorbed 1.02% water after 24 hours, and this percentage remained constant. In this context, it was observed that the water absorption is significantly higher in all of the loaded groups than in neat cellulose acetate. This is to be expected, given that PEG1500 has a hydrophilic structure. As shown in Figure 5, the water uptake ratio of the group with 10% PEG addition (CAP10) was 4–9% higher than that of the group with 5% PEG addition (CAP5).

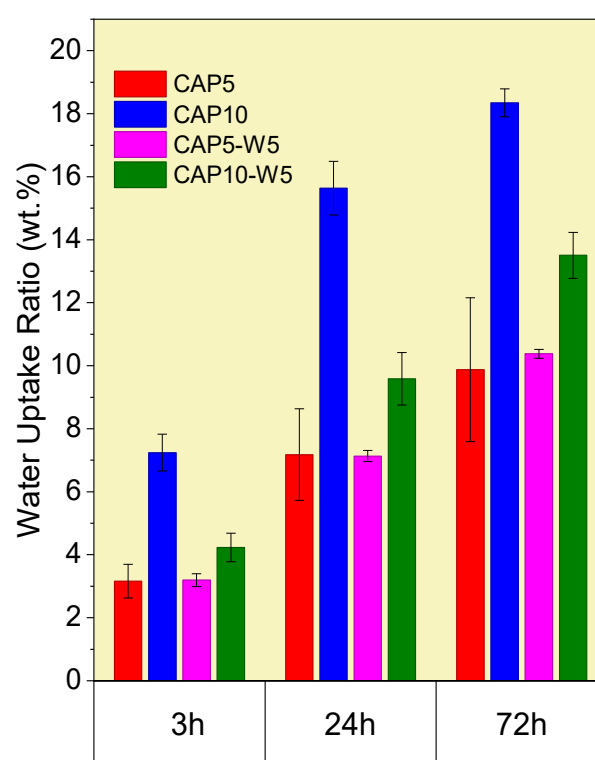


Figure 5: Water uptake ratio of CPLE/PEG loaded Cellulose Acetate

Adding CPLE to the group containing 5% PEG (CAP5-W5) did not significantly affect water uptake behaviour. However, it was observed that the CPLE additive significantly reduces the water absorption rate in composites containing 10% PEG (CAP10-W5). When the CAP10 and CAP10-W5 samples were compared, it was found that the water uptake ratio decreased by 3.01%, 6.06% and 4.84% after 3, 24, and 72 hours, respectively. Due to the extract's wax-like long chain aliphatic structure and low polarity, it is thought to limit water diffusion by forming a tighter structure between polymer chains, especially at high

PEG contents. These results demonstrate that the effect of the extract additive depends not only on the amount of extract but also on the composition of the matrix, and that synergistic effects can be observed at certain ratios. The results were aligned with previous research on the loading of beeswax, palm wax and paraffin wax in polymers (Hafila et. al., 2022, Hromiš et. al., 2015; Lesar & Humar, 2011). High water uptake may reduce mechanical strength and it can facilitate biodegradation (by fungi and bacteria) and shorten the lifetime of the material. This issue is particularly critical for biopolymers, and the development of natural and cost-effective agents that can reduce the interaction between the material and water is of great importance.

4. Conclusion

In this study, the thermal and water uptake behaviors of cellulose acetate composites prepared with the addition of PEG1500 and CPLE, a natural and biodegradable additive, were investigated. It was demonstrated that the addition of PEG1500 decreased the glass transition temperature (T_g). This is because PEG1500 has a plasticizing effect that makes polymer chains more mobile. It was discovered that adding CPLE to the structure raised the T_g values by up to 65°C, especially in groups with a high PEG content. The wax-like extract gives the structure stiffness and restricts the movement of the chains, which causes this rise. In water uptake tests, the effect of CPLE was limited in groups with 5% PEG content. However, a significant decrease in water absorption was observed in composites with 10% PEG content when CPLE was added. On the other hand, the material initially exhibited water-resistant behavior and prolonged exposure led to a drop in its performance so it can no longer be considered fully water-resistant based on the 3-hour water uptake results. Considering the overall evaluation, these materials hold significant potential for deployment in sustainable and eco-conscious applications, particularly in high-humidity settings. Thanks to its properties, such as biodegradability and a non-toxic composition, it has a wide range of potential applications, including food packaging, single-use bioplastics, packaging for personal care products, and healthcare applications. Furthermore, it holds significant potential for creating sustainable biopolymers as substitutes for plastics derived from petroleum. Thus, it can be said that the biocomposite system created in this study is a material that is beneficial from both an industrial and environmental standpoint, with scope for further development. Future research should concentrate on using PEG to chemically modify cellulose acetate and

to examine the mechanical characteristics of the resulting products.

Article Information

Financial Disclosure: The author (s) has no received any financial support for the research, authorship or publication of this study.

Authors' Contribution: Concept: N.A.; Design: N.A.; Supervision: N.A.; Resources: N.A.; Data Collection: N.A.; Analysis: N.A.; Literature Search: N.A. ; Writing Manuscript: N.A.; Critical Review: N.A.

Conflict of Interest/Common Interest: No conflict of interest or common interest has been declared by the authors.

Ethics Committee Approval: This study does not require ethics committee permission or any special permission.

Artificial Intelligence Statement: The author(s) bear full responsibility for the content and accuracy of their work, including any use of artificial intelligence (AI) technologies, and confirm that they have read the AI Policy, which is accessible on the journal's website.

References

- Angin, N., Çaylak S., & Ertaş, M. (2019). Studies on thermal and morphological properties of polyurethane foam filled polypropylene/poly (lactic acid) blends. *Journal of Innovative Science and Engineering* 3(2): 47-56.
- Alkan, C., Kaya, K., & Sarı, A. (2009). Preparation, thermal properties and thermal reliability of form-stable paraffin/polypropylene composite for thermal energy storage. *Journal of Polymers and the Environment*, 17(4), 254–258.
- Arundati, A. H., Ratri, C. R., Chalid, M., Aqoma, H., & Nugraha, A. F. (2024). A combination of nonsolvent and thermally induced phase separation (N-TIPS) technique for the preparation of highly porous cellulose acetate membrane as lithium-ion battery separators. *Ionics*, 30(1), 123–133.
- Candido, R. G., Godoy, G. G., & Goncalves, A. R. (2017). Characterization and application of cellulose acetate synthesized from sugarcane

- bagasse. *Carbohydrate Polymers*, 167, 280–289.
- Erdmann, R., Kabasci, S., & Heim, H.-P. (2021). Thermal properties of plasticized cellulose acetate and its β -relaxation phenomenon. *Polymers*, 13(9), 1356.
- Hanna, A. A., Basta, A. H., El-Saied, H., & Abadir, I. F. (1999). Thermal properties of cellulose acetate and its complexes with some transition metals. *Polymer Degradation and Stability*, 63(2), 293–296.
- Hafila, K. Z., Jumaidin, R., Ilyas, R. A., Selamat, M. Z., & Yusof, F. A. M. (2022). Effect of palm wax on the mechanical, thermal, and moisture absorption properties of thermoplastic cassava starch composites. *International Journal of Biological Macromolecules*, 194, 851-860.
- Hromiš, N. M., Lazić, V. L., Markov, S. L., Vaštag, Ž. G., Popović, S. Z., Šput, D. Z., ... & Popović, L. M. (2015). Optimization of chitosan biofilm properties by addition of caraway essential oil and beeswax. *Journal of Food Engineering*, 158, 86-93.
- Kamide, K., & Saito, M. (1985). Thermal analysis of cellulose acetate solids with total degrees of substitution of 0.49, 1.75, 2.46, and 2.92. *Polymer Journal*, 17(8), 919–928.
- Lesar, B., & Humar, M. (2011). Use of wax emulsions for improvement of wood durability and sorption properties. *European Journal of Wood and Wood Products*, 69(2), 231-238.
- Li, R., Wu, Y., Bai, Z., Guo, J., & Chen, X. (2020). Effect of molecular weight of polyethylene glycol on crystallization behaviors, thermal properties and tensile performance of polylactic acid stereocomplexes. *RSC Advances*, 10(69), 42120–42127.
- Madhushree, M., Vairavel, P., Mahesha, G. T., & Bhat, K. S. (2024). A comprehensive review of cellulose and cellulose-based materials: Extraction, modification, and sustainable applications. *Journal of Natural Fibers*, 21(1), 2418357.
- Oprea, M., & Voicu, S. I. (2020). Recent advances in composites based on cellulose derivatives for biomedical applications. *Carbohydrate Polymers*, 247, 116683.
- Partheniadis, I., Toskas, M., Stavras, F.-M., Menexes, G., & Nikolakakis, I. (2020). Impact of hot-melt-extrusion on solid-state properties of pharmaceutical polymers and classification using hierarchical cluster analysis. *Processes*, 8(10), 1208.
- Righetti, M. C., Cinelli, P., Mallegni, N., Massa, C. A., Aliotta, L., & Lazzeri, A. (2019). Thermal, mechanical, viscoelastic and morphological properties of poly (lactic acid) based biocomposites with potato pulp powder treated with waxes. *Materials*, 12(6), 990.
- Septevani, A. A., & Bhakri, S. (2017). Plasticization of poly (lactic acid) using different molecular weight of Poly (ethylene glycol). *AIP Conference Proceedings*, 1904(1), 020038.
- Tristantini, D., & Yunan, A. (2018). Advanced characterization of microbeads replacement from cellulose acetate based on empty fruit bunches and dried jackfruit leaves. *E3S Web of Conferences*, 67, 04045.
- Zhang, Y., Simpson, B. K., & Dumont, M.-J. (2018). Effect of beeswax and carnauba wax addition on properties of gelatin films: A comparative study. *Food Bioscience*, 26, 88–95.
- Zhang, Z. (2024). Comparison and investigation of edible hydrophobic coatings on beeswax and carnauba wax oil gels. *Applied and Computational Engineering*, 58, 237-242.