University of Sistan and Baluchestan

Challenges in Nano and Micro Scale Science and Technology

Online ISSN: 2821 - 000X

Physical and Mechanical Properties of Nanocomposite Films for Sustainable Packaging: An Innovative Biodegradable Nano smart Packaging Approach

Fatemeh Gharahdaghigharahtappeh[1] | Seyed Ebrahim Hosseini[2]✉ | Gholamhassan Asadi[3] | Zhaleh Khoshkhoo[4]

1. Department of Food Science and Technology, SR.C., Islamic Azad University, Tehran, Iran.
2. Corresponding Author, Department of Food Science and Technology, SR.C., Islamic Azad University, Tehran, Iran. Email: ebhoseini@srbiau.ac.ir
3. Department of Food Science and Technology, SR.C., Islamic Azad University, Tehran, Iran.
4. Department of Food Science and Technology, NT.C., Islamic Azad University, Tehran, Iran.

Article Info

Article type:
Research Article

Keywords:
Eco-compatible,
Eco-friendly,
Nanoanthocyanin,
Nanomaterials,
Polylactic acid

ABSTRACT

In recent years, there has been a growing interest in the development of eco-compatible nanomaterials in the packaging industry to reduce organic waste. One area of research is smart and biodegradable nanofilms, which hold significant potential for reducing agricultural waste and accelerating the decomposition of organic waste from agricultural products and food. In addition, the usage of nanocomposites in packaging is effective in maintaining the quality of food and its shelf life. The aim of this study is to introduce a nanocomposite film of polylactic acid (PLA)/carbopol/nanoanthocyanin to produce an innovative product in the packaging industry with biodegradable and green coatings. In this study, parameters such as oxygen permeation, turbidity, transparency, thickness, tensile strength, water absorption, and water vapor permeability of the films were evaluated. The results showed a significant difference at the 5% level in the tensile strength between the control and the biodegradable films. There was also a significant difference at the 1% level in the water absorption rate between the control and biodegradable films, with the treatment (T1) and control samples having the highest (%18.44 and %19.01), respectively, and the treatment (T4) having the lowest (%10.45). The combination of nano film PLA/carbopol/nanoanthocyanin in (T4) exhibited unique properties compared to other samples. In this film, although PLA and carbopol increased the mechanical strength of (T4), its biodegradability properties can accelerate the degradation process of the nanofilms. Consequently, the packaging coatings decompose easily without harming the environment.

INTRODUCTION

Smart packaging utilizing nanocomposites represents a significant innovation in the food industry, leveraging nanotechnology to enhance both the quality and shelf life of food products. This technology gained attention in the early 21st century and, with advancements in nanomaterials, has found extensive applications in food packaging[1, 2].

The importance of this research can be examined from several perspectives. First, extending food shelf life, as nanocomposites can prevent oxygen and moisture infiltration, thereby reducing food spoilage[3]. Second, reducing plastic waste, as replacing conventional plastics with biodegradable polymers helps minimize environmental harm and supports sustainable development. Third, enhancing mechanical and thermal properties, since the incorporation of nanoparticles strengthens packaging resistance, facilitating broader application. Finally, antimicrobial functionality, as certain nanocomposites possess antimicrobial properties that inhibit bacterial and fungal growth, thereby improving food safety[4, 5]. Eco-friendly nanocomposite films have garnered significant attention in recent years due to their potential applications in various fields, including agricultural product packaging, food packaging, biomedical applications, and drug delivery systems[6]. Polylactic acid (PLA) is a biodegradable polymer widely used in various industries. Additionally, Carbopol is a synthetic polymer known for its excellent film-forming ability and viscosity control[7]. On the other hand,

How to Cite this paper: Gharahdaghigharahtappeh F., Hosseini S.E., Asadi Gh., Khoshkhoo Zh. Physical and Mechanical Properties of Nanocomposite Films for Sustainable Packaging: An Innovative Biodegradable Nano smart Packaging Approach. *Challenges in Nano and Micro Scale Science and Technology*. 2024; 12(1): 12-18. DOI: 10.22111/cnmst.2025.51920.1262

© Gharahdaghigharahtappeh F., Hosseini S.E., Asadi Gh., Khoshkhoo Zh. Publisher: University of Sistan and Baluchestan.

DOI: 10.22111/cnmst.2025.51920.1262

anthocyanin is a natural pigment derived from plants, noted for its antioxidant and antimicrobial properties. Numerous studies have focused on the physical properties of nano films, such as transparency, color stability, water vapor permeability, and oxygen barrier properties[8].

Transparency is an essential feature for agricultural and food packaging materials, as it allows consumers to visually assess the quality of the packaged product[8, 9]. Researchers have found that incorporating nanoanthocyanin into the PLA/Carbopol matrix can enhance transparency while maintaining good mechanical strength[9].

Water vapor permeability (WVP) is a critical characteristic for agricultural, medical, pharmaceutical, and food packaging materials, as it affects the shelf life and quality of perishable products. Researchers

have reported that the PLA/Carbopol combination can significantly reduce WVP, thereby improving the barrier properties of the smart film[9, 10].

Oxygen barrier properties are also crucial in the packaging industry, as they prevent oxygen ingress, which can lead to spoilage and degradation of products. The incorporation of nanoanthocyanin into the PLA/Carbopol layers is believed to enhance their oxygen barrier performance due to improved intermolecular interactions and reduced crystallinity[11].

In assessing the mechanical properties of nanocomposite films like PLA/carbopol/nanoanthocyanin, it is important to evaluate tensile strength, elongation at break, and Young's modulus to determine their mechanical performance. Tensile strength measures the maximum stress a material can withstand before breaking, and incorporating nanoanthocyanin into the PLA/Carbopol matrix can potentially increase tensile strength due to improved surface adhesion between components[10].

Elongation at break, a measure of a material's ability to stretch before breaking, may also be enhanced by adding nanoanthocyanin, making the smart film more flexible and less prone to breakage. Since Young's modulus is a measure of a material's stiffness or rigidity, the incorporation of nanoanthocyanin into the PLA/Carbopol matrix can reduce Young's modulus, resulting in a more flexible and elastic smart film[11].

According to a research by Zhang et al. about smart film made of a biodegradable polymer containing anthocyanins from roselle. They used chitosan, polyvinyl alcohol, and starch to create a variety of films. The starch/polyvinyl alcohol/anthocyanin film had the highest antioxidant activity (0.7524%), whereas the polyvinyl alcohol/chitosan/anthocyanin roselle film had the highest tensile strength (28.98 MPa)[12].

Wu et al. created a smart film based on chitosan (CS) and oxidized chitin nanocrystals (O-ChNCs) that included 1, 3, and 5% black rice bran anthocyanins (BACNs). The findings demonstrated that while the inclusion of BACNs decreased the mechanical properties of CS/O-ChNCs/BACNs films, it gave the desired antioxidant, pH sensitivity, and UV resistance[13].

Mahmoodi et al. created high-strength, low-permeability, and light-protective nanocomposite films for food packaging using hybrid nano-pigments and biodegradable PLA. They combined dye-clay nanopigments (DCNP) as a multipurpose filler with PLA to generate a colored film that is both biodegradable and biocompatible. The results demonstrated that the incorporation of a small amount of DCNP into the PLA matrix significantly reduced water vapor and gas permeability by 33% and 55%, respectively[14].

The research team of Qin et al. prepared films based on starch/polyvinyl alcohol (PVA) and Lycium ruthenicum anthocyanin nanocomplexes. The results showed that the starch/PVA/nanocomposite films (SP-AN) exhibited fine and compact structures, strong intermolecular interactions, superior water vapor blocking capabilities, and better mechanical properties compared to the starch/PVA/free anthocyanins film (SP-FA). However, the SP-FA film demonstrated higher light-blocking and antioxidant properties compared to the SP-AN film. They also noted that when the films were exposed to light and a temperature of 35°C for 30 days, the SP-AN film showed greater stability than the SP-FA film[15].

Biodegradable nanocomposites in food packaging represent an emerging and significant area within nanotechnology, playing a crucial role in preserving food quality while mitigating environmental impact. These materials consist of biodegradable polymers combined with nanoparticles such as nanoclay, nanocellulose, and metallic nanoparticles, which enhance the mechanical, thermal, and barrier properties of packaging.

Overall, the physical and mechanical properties of PLA/carbopol/nanoanthocyanin nanocomposite films, aimed at achieving nanosmart packaging for agricultural products, foods, and pharmaceutical industries, with the purpose of reducing waste and accelerating the decomposition of organic materials, have been investigated in this article.

MATERIALS AND METHODS

Preparation of Raw Materials

In this study, papaver petals were collected in early May from the Noshahr Botanical Garden, located near the Caspian Sea, with the geographical coordinates (UTM) (Zone: 39S Easting: 545628.00 m E

Northing: 4055673.00 m N). After separating the stamens and sepals, all petals were transferred to the laboratory after three days of shade drying.

Extraction of papaver nanoanthocyanin

For the extraction of nanoanthocyanin, 10 g of papaver sample and 40 ml of ethanol solvent were placed in an ultrasonic wave generator model Q125 (Qsonica, USA). Sonication was carried out for 2 min at ultrasound intensities of 200 W/m2. The absorption of nanoanthocyanin was measured at wavelength of 520 nm and pH= 1 using a spectrophotometer (model 1900i (Shimadzu, Japan, and the extracted nanoanthocyanin was used to prepare the nanocomposite films[16].

Preparation of Control and Biodegradable Nanocomposite Films

The casting method with solvent was used to produce the control and biodegradable smart films. 5 g of carbopol-polylactic acid granules were added to 100 ml of chloroform, and the resulting mixture was applied to the magnetic mixer at ambient temperature for 8 hours. Then the desired concentrations of nanoanthocyanin were added, and the resulting mixture was placed on the magnetic mixer for another 20 min. Finally, it was homogenized with a homogenizer for 2 min with a circumference of 12,000 rpm. When nanoanthocyanin was added to the final solution, it was uniformed at RPM 8000 for 10 min, and the degasification was performed by the sonicator for 30 min at room temperature. The solution was then poured into glass molds and stored for 4 h at room temperature under the fume hood. After the solvent evaporated, the film was separated from the molds and placed at room temperature for 24 h to completely remove the solvent residue, which may play a plasticizer role[17].

The preparation steps for raw materials and the production of films are illustrated in Fig.1. The nanocomposite films of PLA, PLA/Carbopol, and PLA/Carbopol/Nanoanthocyanin were prepared using the above method in different ratios as specified in (Table 1) and were encoded.

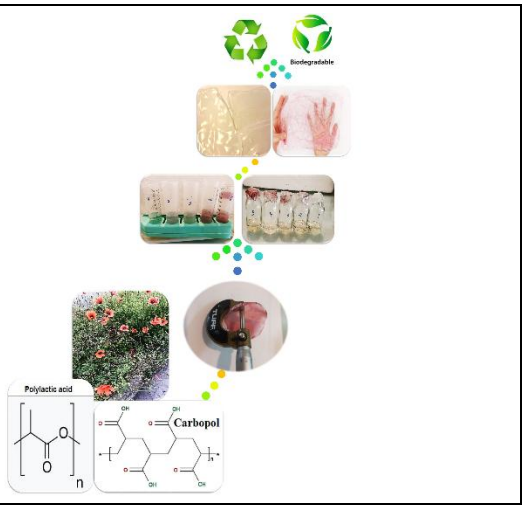


Fig.1. Preparation of Raw Materials, Production of Control, and Biodegradable Nanocomposite Films and Tests

Table 1
Principles of the Nomenclature of Control and Biodegradable Nanocomposite Films

Treatment number	Symbol	Combination/Percentage
1	T_0	control (5% polylactic acid, 0% carbopol, 0% nanoanthocyanin)
2	T_1	4.8% polylactic acid, 0.2% crobopol, 0% nanoanthocyanin
3	T_2	4.8% polylactic acid, 0.2% carbopol, 0.5% nanoanthocyanin
4	T_3	4.8% polylactic acid, 0.2% crobopol, 1% nanoanthocyanin
5	T_4	4.8% polylactic acid, 0.2% carbopol, 2% nanoanthocyanin

Physical and Mechanical Properties of Control and Biodegradable Nanocomposite Films Tests

Oxygen Permeation (OP): The oxygen permeability of the control film and the biodegradable nano film was indirectly measured using the Ou method. The vials were filled with 10 mL of pure oleic acid. A piece of the films was placed into vial caps with 8 mm diameter perforations. Then, the caps containing the films were completely sealed onto the vials. The vials were placed in an incubator with a temperature of 25±1 ˚C and a relative humidity of 55% for 20 days. After the desired period of time, the amount of oleic acid peroxide in the vial was measured according to the AOAC 1990 method and reported as the measure of film permeability to oxygen[15, 18].

Turbidity: The turbidity measurement of the control film and the biodegradable composite film was conducted according to the ASTM D10030-00 Standard. To determine turbidity, the films were cut into the dimensions of the spectrophotometer cell model 1900i (Shimadzu, Japan) and placed inside the UV Vis cell (empty cell as a witness), and the amount of light absorption was read at a wavelength of 800- 400 nm. Then the following equation (1) was used to determine turbidity[14].

$$\%\ \text{Turbidity} = \frac{\text{absorption percentage}}{\text{Thickness}} \qquad \text{Eq (1)}$$

Transparency: To measure transparency, the control film and the biodegradable nano film were cut into strips with the dimensions of the spectrophotometer cell model 1900i (Shimadzu, Japan), placed inside the spectrophotometer cell, and an empty cell was used as a reference. The absorption rate in the wavelength range of 800-400 nm was performed in three repetitions, and the film transparency rate was determined using the following equation (2)[12, 18].

$$\text{Transparency} = \frac{\text{absorption percentage} - 100}{\text{Thickness}} \qquad \text{Eq (2)}$$

Thickness: The thickness of the control and biodegradable nanocomposite films was measured using a micrometer Model YWK2123 (MeterTo, China) with an accuracy of 0.01 mm at four different points on the samples. The average thickness of different points on each film was used in calculating the characteristics of mechanical tests and water vapor permeability[19, 20].

Water Absorption (WA): samples were prepared in dimensions of 2×2 cm and placed in a desiccator for 24 hours. The samples were then weighed with a digital scale, Model HR200 (AND, China), with an accuracy of 0.0001, to calculate their initial weight. The samples were then placed in a lid container containing 30 ml of distilled water at 7 pH and at a temperature of 25°C. In order to determine the amount of WA, the films were periodically removed from the container at certain intervals and weighed until they reached a constant weight. At the end, the amount of WA from the following equation (3) was calculated[18, 21].

$$\%\ \text{Water absorption} = \frac{\text{preimmersion weight} - \text{postimmersion weight}}{\text{preimmersion weight}} \times 100 \qquad \text{Eq (3)}$$

Water Vapor Permeability (WVP): The water vapor permeability test for the control film and the biodegradable nano film was conducted according to the ASTM15009:E96 standard. To perform the

test, glass cups with an internal diameter of 3 cm and a height of 3.5 cm were used. 10 g of silica gel were poured into the cups to create a relative humidity of 1% in the space inside the cup. Then the films were placed on the cups and taped with glue, tightened, and sealed. The cups were then inserted into the desiccator, which contained a saturated solution of sodium chloride with a relative humidity of 75±3. The desiccator was placed inside the oven at a temperature of 25 °C. The cups were calculated at specific time intervals with a scale with an accuracy of 0.0001 g until reaching a constant weight, weight, and water vapor transfer rate through the following equation (4):

$$WVP = \Delta m \times XA \times \Delta t \times \Delta m \qquad \text{Eq (4)}$$

In this regard,

Δm = cup-related weight loss

A = exposed surface (7.06 cm²)

Δt = time

X = Thickness

ΔP = partial pressure difference between the inside and outside of the cup (pressure difference at 100% humidity and 25°C temperature, 3.179 KPa (using the saturated steam table) was considered)[18].

Tensile Strength: The tensile strength measurement of the control film and the biodegradable nonocomposite film was conducted according to the modified ASTM D0882-02 method. The films were cut into 7×1 cm pieces and conditioned under conditions of 50% relative humidity and a temperature of 25 °C. Before the stretch test, the thickness of the films was determined by at least three measuring points and the average thickness. Then, in the Instron model 4400 (Instron, USA), the distance between the two jaws was set at 50 mm/min, the upper jaw was set at 50 mm/min, and the lower jaw was fixed. The degree of elasticity (percentage) is obtained by dividing the degree of elasticity at the moment of ripping of the film sample by the initial length of the film, the resistance to elasticity (MPa) by dividing the maximum force by the initial surface, and the elastic modulus (MPa), the slope of the first part of the curve with a constant slope, is obtained by following equations (5,6)[19, 20].

$$\text{TS} = \frac{\text{Maximum load}}{\text{Original.minimum.cross.sectional.area}} = \frac{\Delta L}{L} \times 100 \qquad \text{Eq(5)}$$

$$\%\text{E} = \frac{\textbf{Extension at moment of rupture}}{\text{initial gage lengh}} = \frac{\Delta L}{L} \times 100 \qquad \text{Eq(6)}$$

ΔL = the ratio of the tension to the moment of the rupture in mm.

L = the initial length of the film or the initial distance between the two jaws in mm.

E = without dimension.

Statistical analysis

All tests were performed based on a completely randomized design with 5 treatments and 3 repetitions (except for the thickness test with 4 repetitions) using SPSS version 26. The one-way ANOVA method was used to calculate the variance of the data at a significance level of α = 0.05, and the Duncan's multiple range test was used to determine the mean comparisons in order to investigate the presence of significant differences in the results.

RESULTS AND DISCUSSION

Oxygen Permeation**:** According to the results of a one-way ANOVA analysis of variance test (Table 2) for oxygen penetration of the control films and the biodegradable nano films, there is a significant difference between the groups at the 1% level. Additionally, based on the results of Duncan's test for comparing the means of the data (Table 3), it can be concluded that there is no significant difference between treatments (T4) and (T3). However, there is a significant difference between the control sample and treatments (T1) and (T2).

Table 2

Analysis of Variance for Physical and Mechanical Properties of Control and Biodegradable Nanocomposite Films

Test Type	Source of Variation	Sum of Squares	df	Mean Squares	F	Sig
Oxygen Permeation	Treatment	10.337	4	2.584	68.009	0.000 **
	Error	0.38	10	0.38		
	Total	10.717	14			
Turbidity	Treatment	5.294	4	1.324	3374.84	0.000 **
	Error	0.004	10	0.00039		
	Total	5.293	14			
Transparency	Treatment	445.246	4	111.312	283797.09	0.000 **
	Error	0.004	10	0.00039		
	Total	445.25	14			
Thickness	Treatment	0.00002	4	0.00005	0.044	0.996 ns
	Error	0.0017	15	0.000113		
	Total	0.00172	19			
Water Absorption	Treatment	214.031	4	53.508	96.916	0.000 ns
	Error	5.521	10	0.552		
	Total	219.552	14			

Water Vapor Permeability	Treatment	0.92095	4	0.023015	286.85	0.000 **
	Error	0.000802	10	0.000082		
	Total	0.092861	14			
Tensile Strength	Treatment	1.837	4	0.031	4.408	0.02 ns
	Error	42.994	10	0.006		
	Total	44.782	14			

** Significant difference at the 1% probability level, *: significant difference at the 5% probability level, ns: non-significant difference.

As shown in (Table 3), there is a decreasing trend in the oxygen permeability of the films. The highest level of oxygen permeability is observed in the control sample (T0), while the lowest level is observed in the treatment sample (T4). In other words, the increase in the level of nanoanthocyanin derived from papaver in biodegradable nanocomposite films compared to the control film has reduced oxygen absorption capability. This, in turn, can decrease the oxidation and spoilage processes of packaged agricultural, pharmaceutical, and food products. Therefore, it can be used for packaging food, especially products sensitive to spoilage such as fruits, vegetables, fish fillets, meat, and pharmaceutical industry.

Overall, it can be stated that the smart film containing 2% nanoanthocyanin from papaver is more effective in reducing oxygen permeability compared to other samples, making it recommended for packaging agricultural, pharmaceutical, and food products.

Table 3
Comparison of Means of Physical and Mechanical Properties of Control and Biodegradable Nanocomposite Films

Treatment	Oxygen Permeation	Turbidity	Transparency	Thickness	Water Absorption	Water Vapor Permeability	Tensile Strength
T_0	3.7333 [e]	0.3333 [a]	713.95 [e]	0.14 [a]	18.44 [b]	33.704 [a]	0.4073 [b]
T_1	3.2667 [d]	0.7415 [b]	701.01 [d]	0.1425 [a]	19.0133 [b]	33.7554 [b]	0.2512 [a]
T_2	2.7 [c]	1.2 [c]	700.55 [c]	0.1425 [a]	17.9467 [b]	33.8294 [c]	0.1866 [a]
T_3	1.8 [b]	1.5649 [d]	700.19 [b]	0.1425 [a]	11.1467 [a]	33.89 [d]	0.1891 [a]
T_4	1.5667 [a]	2.0211 [e]	699.73 [a]	0.1425 [a]	10.4533 [a]	33.91 [e]	0.1537 [a]

The texts with common letters have no significant difference in meaning. α = 5%

Turbidity: Based on (Table 2), the results of the one-way analysis of variance for the turbidity test of the films indicate that there is a significant difference at the 1% level among the groups. As shown in (Table 3), there is an upward trend in the turbidity levels of the films. The lowest turbidity level is associated with the control sample (T0), while the highest level is associated with treatment (T4). Therefore, it can be acknowledged that an increase in the percentage of nanoanthocyanins in the films has also led to an increase in turbidity (positive correlation). Thus, the nanocomposite film containing 2% nanoanthocyanins from papaver has the highest turbidity compared to other samples. This can be attributed to the increased level of nanoanthocyanins on the nano film.

Transparency: Similarly, the results of the one-way ANOVA test (Table 2) for the transparency of the control films and the biodegradable nano films indicate a significant difference between the groups at the 1% level. On the other hand, according to (Table 3), comparing the means of the data obtained from the Duncan test, it can be concluded that there is a significant difference between all groups. As shown in (Table 3), there is a downward trend in the transparency level of the films. The lowest transparency level is observed in the control group (T4), while the highest level is associated with the control sample (T0), which can be attributed to the absence of anthocyanins/carbopol in the control film (negative correlation).

Thickness: According to (Table 2), the one-way ANOVA results for the thickness of the control films and the biodegradable nanocomposite films show that there is no significant difference in film thickness at the 5% level. According to (Table 3), it can be observed that there is no significant difference in the thickness of the films between the control sample (T0) and the treatments (T1), (T2), (T3), and (T4). Therefore, the increase in nanoanthocyanins/carbopol levels did not have a noticeable effect on the thickness of the control films and the nano films of PLA/carbopol/nanoanthocyanin.

Water absorption: The analysis of the one-way ANOVA results (Table 2) for the WA of the control films and the biodegradable nanocomposite films indicates a significant difference in WA levels between the groups at the 1% level. Additionally, there is no significant difference in WA levels between treatments (T3) and (T4). Furthermore, there is no significant difference between the control sample (T0) and the treatments (T1) and (T2). However, there is a significant difference between (T0), (T1), (T2), and treatments (T3) and (T4). According to (Table 3), it can be observed that there is a decreasing trend in WA of films, where the (T4) treatment has the lowest WA and the control sample has the highest WA (negative correlation). Therefore, the increased levels of PLA/carbopol/nanoanthocyanin prevent water absorption in biodegradable nano films, which can delay the spoilage of packaged products such as pharmaceuticals, agricultural products, and food products. Consequently, nanocomposite films containing 1% and 2% nanoanthocyanin derived from papaver are considered the best films for reducing WA and are recommended for the packaging industry with the aim of delaying spoilage and increasing shelf life.

Water vapor permeability: As shown in (Table 2), the results show that there is a significant difference in WVP between the control films and the biodegradable nanocomposite films at the 1% level. Additionally, according to (Table 3), a comparison of the average data

reveals that there is a significant difference among all groups. The results indicate an upward trend in the WVP of the films. With an

increase in levels of PLA/carbopol/nanoanthocyanin, the control sample (T4) has the highest WVP (positive correlation). In other words, the control sample containing 5% PLA has lower WVP compared to the biodegradable nano films. On the other hand, films containing 2% nanoanthocyanin from papaver are considered desirable in terms of WVP. These results are consistent with the research conducted by Qin et al. and mahmoodi et al. [14, 15].

Tensile strength of the film: The ANOVA analysis results for the tensile strength of the control films and the biodegradable nano films indicate a significant difference in the tensile properties of the films at the 5% level. According to (Table 3), there is an upward trend in the tensile strength of the films. The lowest tensile strength is observed in the control sample (T0), while the highest tensile strength is observed in the treatment (T4). Therefore, it can be stated that the increase in the levels of PLA/carbopol/nanoanthocyanin leads to an increase in the length during stretching and an increase in the tensile strength. In other words, the surface adhesion between the layers has increased, and the nanocomposite films have become more flexible, making them less prone to breakage. Additionally, with the increase in PLA/carbopol/nanoanthocyanin levels and the enhancement of tensile properties of the biodegradable nano films, the Young's modulus also decreases, resulting in more elastic nanocomposite films. Therefore, it can be stated that the biodegradable nano film containing 2% nanoanthocyanin derived from papaver possesses the best tensile properties compared to other samples and is recommended for packaging various products. These findings are consistent with the research conducted by by Qin et al., mahmooi et al. and zhang[12, 14, 15].

CONCLUSION

Investigating the physical and mechanical properties of the biodegradable nanocomposite film composed of PLA/Carbopol/Nanoanthocyanin has shown promising results for its potential applications in the packaging industry. However, further research is needed to optimize the formulation and processing conditions to achieve desirable properties for specific applications. Despite the promising features and applications of PLA/Carbopol nano films, there are still challenges that need to be addressed. One of the main challenges is the limited understanding of the degradation behavior of the film and its impact on the kinetics of certain products. Therefore, more research is required to optimize

the degradation rate of the film for specific applications. As the results demonstrated, the incorporation of nanoanthocyanin improves water vapor permeability (%33.91), reduces oxygen absorption (%10.45), and enhances tensile strength (%0.15). The treatment (T4) containing 4.8% PLA, 0.2% carbopol, and 2% nanoanthocyanin is identified as the optimal biodegradable nano film. Nevertheless, further efforts are needed to improve the mechanical strength of these films to ensure their long-term stability. Understanding the physical and mechanical properties of this biodegradable nanocomposite film paves the way for its potential applications in the pharmaceutical packaging industry, agricultural products, and food, etc. The findings of this study contribute to the development of advanced materials that can revolutionize fields such as healthcare, packaging technology, environmental sustainability, and the reduction of hazardous waste in the environment. Therefore, it is suggested that future research should aim to design this film with specific features such as controlled release of bioactive compounds, increased mechanical strength, and enhanced barrier properties against water and oxygen penetration, enabling faster degradation in nature and providing a type of eco-compaitable packaging that reduces organic waste. These characteristics would facilitate faster degradation in nature, thereby offering an eco-friendly packaging solution that effectively reduces organic waste. Consequently, it is advised that biodegradable nanocomposite films like PLA/Carbopol/Nanoanthocyanin be investigated not only for agricultural and food packaging applications but also for potential biomedical uses.

ACKNOWLEDGEMENTS

We would like to express our gratitude to the "Mizan Sanjesh Pars" laboratory for assisting us in experiments and greatly raising the caliber of the research report.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

REFERENCES

[1] Valayat Zadeh M. Review of nanotechnology and smart packaging applications in food preservation. Res Surf Eng Nanomater 2023;1(2):15–25.

[2] Sadeghizadeh-Yazdi J, Nayik GA, Hajimirzadeh MS, et al. Application of nanomaterials in food packaging: a review study. SSU-JFQHC 2024;11:149–56.

[3] Sarfraz J, Gulin-Sarfraz T, Nilsen-Nygaard J, et al. Nanocomposites for food packaging applications: an overview. Nanomaterials 2020;11(1):10. https://doi.org/10.3390/nano11010010

[4] Chauhan P, Chauhan E, Singh P. A review of nanotechnology applications in food processing, packaging, and preservation. Adv Res 2024;25:427–41.

[5] Dera M, Bogale W. Review on the application of food nanotechnology in food processing. Am J Eng Technol Manag 2020;5:41.

[6] Zabidi N'A, Nazri F, Tawakkal ISMA, et al. Characterization of active and pH-sensitive poly(lactic acid) (PLA)/nanofibrillated cellulose (NFC) films containing essential oils and anthocyanin for food packaging application. Int J Biol Macromol 2022;212:220–31.

[7] Wu L-T, Tsai I-L, Ho Y-C, et al. Active and intelligent gellan gum-based packaging films for

controlling anthocyanins release and monitoring food freshness. Carbohydr Polym 2021;254:117410.
[8] Zhao Y, Du J, Zhou H, et al. Biodegradable intelligent film for food preservation and real-time visual detection of food freshness. Food Hydrocoll 2022;129:107665.
[9] de Oliveira Filho JG, Bertolo MRV, Rodrigues MÁV, et al. Recent advances in the development of smart, active, and bioactive biodegradable biopolymer-based films containing betalains. Food Chem 2022;390:133149.
[10] Taghinia P, Abdolshahi A, Sedaghati S, et al. Smart edible films based on mucilage of Lallemantia iberica seed incorporated with curcumin for freshness monitoring. Food Sci Nutr 2021;9:1222–31.
[11] Tao F, Shi C, Cui Y. Preparation and physicochemistry properties of smart edible films based on gelatin–starch nanoparticles. J Sci Food Agric 2018;98:5470–8.
[12] Zhang J, Zou X, Zhai X, et al. Preparation of an intelligent pH film based on biodegradable polymers and roselle anthocyanins for monitoring pork freshness. Food Chem 2019;272:306–12.
[13] Wu C, Sun J, Zheng P, et al. Preparation of an intelligent film based on chitosan/oxidized chitin nanocrystals incorporating black rice bran anthocyanins for seafood spoilage monitoring. Carbohydr Polym 2019 Oct 15;222:115006.
[14] Mahmoodi A, Ghodrati S, Khorasani M. High-strength, low-permeable, and light-protective nanocomposite films based on a hybrid nanopigment and biodegradable PLA for food packaging applications. ACS Omega 2019;4:14947–54.
[15] Qin Y, Yun D, Xu F, et al. Smart packaging films based on starch/polyvinyl alcohol and Lycium ruthenicum anthocyanins-loaded nano-complexes: functionality, stability and application. Food Hydrocoll 2021;119:106850.
[16] Zou T-B, Wang M, Gan R-Y, et al. Optimization of ultrasound-assisted extraction of anthocyanins from mulberry, using response surface methodology. Int J Mol Sci 2011;12:3006–17.
[17] Rhim JW, Hong SI, Park HM, et al. Preparation and characterization of chitosan-based nanocomposite films with antimicrobial activity. J Agric Food Chem 2006;54:5814–22.
[18] Zabihollahi N, Alizadeh A, Almasi H, et al. Development and characterization of carboxymethyl cellulose based probiotic nanocomposite film containing cellulose nanofiber and inulin for chicken fillet shelf life extension. Int J Biol Macromol 2020;160:409–17.
[19] Jiang G, Hou X, Zeng X, et al. Preparation and characterization of indicator films from carboxymethyl-cellulose/starch and purple sweet potato (Ipomoea batatas (L.) Lam) anthocyanins for monitoring fish freshness. Int J Biol Macromol 2020;143:359–72.
[20] Mahdizadeh A, Shahidi SA, Shariatifar N, et al. Preparation and evaluation of chitosan-zein film containing free and encapsulated ethanol extract of Kak Kosh Biabani (Pulicaria gnaphalodes (Vent.) Boiss). J Med Plants 2020;19:223–38.
[21] Wu C, Sun J, Zheng P, et al. Preparation of an intelligent film based on chitosan/oxidized chitin nanocrystals incorporating black rice bran anthocyanins for seafood spoilage monitoring. Carbohydr Polym 2019;222:115006.