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Investigation of Biodegradation and Physical Properties of PVA/Gelatin Film Incorporating Lemon Peel Extract and Rosehip Seed Oil

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Abstract: Growing environmental concerns regarding petroleum-based food packaging materials have accelerated the search for biodegradable alternatives. In this work, biodegradable films based on poly(vinyl alcohol) (PVA) and gelatin were produced via the solution casting technique and functionalized with lemon peel extract (LPE) and rosehip seed oil (RSO). The effects of polymer blending and natural additives on film thickness, antioxidant activity, water vapor permeability (WVP), and biodegradation behavior were examined. Blending gelatin with PVA caused only minor changes in film thickness, while the incorporation of lemon peel extract resulted in a slight increase from 0.108 mm to 0.115 mm. In contrast, the presence of rosehip seed oil significantly affected the film structure, increasing thickness up to 0.243 mm, corresponding to approximately a 125% increase compared with the gelatin film. The addition of RSO also improved the moisture barrier performance of the films. The WVP value decreased from 18.25×10^{-6} $g \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1}$ for gelatin films to 6.23×10^{-6} $g \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1}$ for RSO-loaded PVA/gelatin films, representing about a 66% reduction in water vapor permeability. Antioxidant activity was strongly influenced by the presence of plant-derived additives. The film containing both LPE and RSO reached 78.67% radical scavenging activity, indicating a substantial improvement in antioxidant capacity due to the presence of bioactive compounds. Soil burial experiments showed that gelatin films degraded rapidly, whereas PVA/gelatin-based films displayed a slower but still biodegradable degradation behavior. These findings demonstrate that combining polymer blending with natural bioactive additives can significantly improve the structural, barrier, and antioxidant properties of biodegradable packaging films.

Keywords: Biodegradable films, PVA/gelatin blend, Lemon peel extract, Rosehip seed oil.

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1. INTRODUCTION

The extensive use of petroleum-based plastics in food packaging has led to serious environmental concerns. These materials are highly resistant to natural degradation and persist in the environment long after disposal. As a result, they accumulate in landfills and contribute to microplastic pollution in both soil and aquatic ecosystems. For this reason, increasing attention has been directed toward the development of biodegradable packaging materials that can decompose under natural conditions and reduce environmental impact (1–4).

PVA has been widely studied for biodegradable film applications because of its good film-forming ability, transparency, and compatibility with natural polymers (5–7). Although PVA shows biodegradation potential, its biodegradation rate is often relatively slow when used alone. The relatively high material cost of PVA has driven research toward PVA-based blends incorporating inexpensive polysaccharides, particularly starch and cellulose, with the aim of reducing cost and modifying degradation characteristics (8–11).

Gelatin, a protein-based polymer derived from collagen, is biodegradable, biocompatible, and suitable for food-contact applications (12). Its

molecular structure contains numerous polar functional groups, which contribute to water affinity and allow the material to interact readily with its surrounding environment. When blended with PVA, gelatin can modify the internal organization of the polymer matrix by promoting intermolecular interactions and increasing matrix accessibility to moisture and microorganisms, factors that are known to influence biodegradation processes. Accordingly, PVA/gelatin blends provide a versatile film-forming system in which structural integrity, moisture sensitivity, and biodegradation behavior can be adjusted simultaneously, making them suitable candidates for biodegradable food packaging applications.

In recent years, the incorporation of natural additives into biodegradable films has attracted increasing interest as a means of modifying film structure and degradation behavior. Citrus processing generates large amounts of peel waste, which are rich in phenolic compounds and organic acids (13,14). Lemon peel extract, in particular, has been reported to exhibit antioxidant activity and high polarity, allowing it to interact with polymer chains and influence film microstructure (15–17). The extraction of secondary metabolites from natural sources has attracted increasing interest in food packaging research due to their functional properties. Plant-derived extracts are rich in bioactive compounds, particularly phenolics, which are known for their antioxidant and antimicrobial activities. When incorporated into packaging materials, these compounds can help slow oxidative degradation and improve the preservation of food products. The growing use of natural extracts in packaging systems reflects the demand for sustainable materials that combine environmental compatibility with functional performance (18–20).

Lemon peel extract contains various phenolic compounds such as flavonoids and phenolic acids, including hesperidin and eriocitrin. These compounds possess multiple hydroxyl (–OH) groups that contribute to their relatively high polarity and antioxidant activity. The presence of these functional groups enables phenolic molecules to interact with the hydroxyl groups of PVA, and the amino and carboxyl groups present in gelatin through hydrogen bonding. Such interactions may influence the internal organization of the polymer matrix and contribute to the antioxidant functionality of the films.

In addition to plant extracts, natural oils have also been explored as functional additives in biodegradable films. Rosehip seed oil, obtained from *Rosa canina* seeds, contains unsaturated fatty acids such as linoleic and oleic acids as well as minor bioactive components including tocopherols. Due to its hydrophobic nature, the incorporation of rosehip seed oil can alter the hydrophilic–hydrophobic balance of polymer films and introduce lipid domains into the polymer matrix. This structural heterogeneity may influence film morphology, moisture transport, and biodegradation behavior (6, 7, 21–23).

Although previous studies have predominantly focused on the effects of plant extracts or natural oils on biodegradable polymer films, studies specifically addressing the combined influence of lemon peel extract and rosehip seed oil on the biodegradation behavior of PVA/gelatin films remain limited. Most studies have investigated the incorporation of a single natural additive, such as plant extracts or essential oils, rather than the simultaneous use of different bioactive compounds within the same polymer matrix. In some cases, the incorporation of hydrophilic plant extracts may increase the water vapor permeability of biopolymer films due to enhanced interactions with water molecules. For instance, Gürler et al. reported that the addition of pineapple peel extract to chitosan/gelatin/starch composite films increased water vapor permeability because of the hydrophilic nature of the extract, which facilitated the diffusion of water molecules within the polymer matrix (24). On the other hand, the incorporation of plant oils has been reported to reduce WVP in biopolymer films. For example, Ghanbarzadeh et al. reported that the addition of grape seed oil and virgin olive oil to gelatin–pectin-based films decreased WVP due to the increased hydrophobicity and the formation of lipid domains within the polymer matrix (25). Therefore, combining plant extracts with hydrophobic oil phases may help balance these effects by improving the moisture barrier properties of the films. Such a strategy may provide complementary functional effects, where phenolic compounds contribute to antioxidant activity while hydrophobic components improve moisture barrier properties and film structure. The simultaneous use of plant extracts and essential oils has also been explored in other biopolymer-based systems. For example, composite chitosan/gelatin films containing perilla essential oil and grape seed extract have been reported to exhibit improved barrier properties and preservation performance in food storage applications (26). Similarly, chitosan/gelatin films incorporating *Ziziphora clinopodioides* essential oil and grape seed extract have been shown to exhibit improved antioxidant, antibacterial, and barrier properties (27).

Based on these considerations, it is hypothesized that incorporating LPE and RSO into PVA/gelatin films may alter the internal structure of the polymer matrix and improve functional properties such as antioxidant activity and moisture barrier performance. Therefore, this study aims to examine the combined effect of LPE and RSO on the physicochemical, antioxidant, moisture barrier, and biodegradation properties of PVA/gelatin biodegradable films. To test this hypothesis, PVA/gelatin films containing these additives were prepared, and their optical, antioxidant, moisture barrier, and biodegradation properties were evaluated.

2. EXPERIMENTAL SECTION

2.1. Material

All chemicals used in this study were of analytical grade. DPPH, ethanol, and methanol were purchased from Sigma-Aldrich. Poly(vinyl alcohol) (PVA; molecular weight 146,000–186,000; purity 99.3–100.0%) was obtained from Thermo Scientific. Fresh lemons were sourced from a local market, and the peels were manually separated, thoroughly washed with distilled water, and used for the preparation of lemon peel extract. Gelatin was obtained from a local supplier and used without further purification. Glycerol, used as a plasticizer, was supplied by Merck. Deionized water was used throughout all experiments. Cold-pressed rosehip seed oil (RHSO) was provided by a local producer.

2.2. Preparation of Lemon Peel Extract

Fresh lemon peels were thoroughly washed with distilled water to remove surface impurities and then cut into small pieces. The prepared peels were ground to obtain a coarse material suitable for extraction. For the extraction process, 10 g of the prepared lemon peel material was mixed with 25 mL of an ethanol–water solution (50:50, v/v). The mixture was subjected to ultrasonic treatment for 40 min to enhance the release of bioactive compounds. After sonication, the extract was separated by filtration, and the solid residue was extracted again under identical conditions to improve extraction efficiency. The filtrates obtained from both extraction steps were combined and concentrated using a water bath at 45 ± 2 °C under continuous stirring until the solvent was almost completely removed and a viscous extract was obtained. The concentration process required approximately 40 min. The concentrated lemon peel extract was then cooled to room temperature and used immediately for film preparation.

2.3. Preparation of Gelatin- and PVA/Gelatin-Based Biodegradable Films

PVA/gelatin-based biodegradable films were prepared using the solution casting method (6,7). An aqueous PVA solution (6% w/v) was prepared by dissolving PVA in deionized water at 90 ± 2 °C for 60 min under continuous magnetic stirring (500 rpm) using a thermostatically controlled hot-plate magnetic stirrer until complete dissolution was achieved. Separately, 3 g of gelatin was dissolved in 50 mL of deionized water at 50 ± 2 °C for 30 min under magnetic stirring (400 rpm). Glycerol was added as a plasticizer at 10 wt% of the gelatin content, and the mixture was stirred until a homogeneous solution was obtained. The PVA and gelatin solutions were then combined at a 1:1 (w/w) ratio to obtain a uniform PVA/gelatin film-forming solution.

For the preparation of active films, LPE was incorporated into the PVA/gelatin solution at 4 wt% of the total polymer content and mixed thoroughly to ensure homogeneous distribution within the polymer matrix. For oil-containing films, RSO was added at 1 wt% of the total polymer content, and the mixture was homogenized using a high-speed homogenizer at 10,000 rpm for 5 min to achieve uniform dispersion of the oil phase in the polymer matrix.

Aliquots of 5 mL of the resulting film-forming solutions were cast onto acrylic casting plates (16 × 60 cm) using a syringe and dried at room temperature for 48 h under dust-free conditions with the casting plates left uncovered to allow completion of solvent evaporation. After drying, the films were carefully peeled from the casting surface and stored under ambient conditions until further characterization.

2.4. Thickness Measurement of Films

Film thickness was determined using a calibrated digital micrometer (Loyka 5202-25). Measurements were taken at five different positions on each sample, and the average value was reported.

2.5. Swelling Ratio of Films

Film specimens (1 × 1 cm) were weighed to obtain the initial mass (W_0) and then placed in 50 mL of distilled water at room temperature. At selected time intervals, the samples were removed, surface water was gently removed using filter paper, and the wet weight (W_w) was recorded. Measurements were continued until swelling equilibrium was achieved.

The swelling percentage (SR%) was calculated using the following equation:

$$Swelling\ ratio\ (\%) = \frac{W_w - W_0}{W_0}\ x\ 100 \quad (1)$$

2.6. Biodegradability Assessment of Films

Film biodegradability was evaluated using the soil burial technique (28). Square film samples (1 × 1 cm) were buried in natural soil at a depth of 15 cm and maintained under moist conditions through periodic watering. At predetermined time intervals (4, 7, 10, and 20 days), the samples were removed from the soil, gently cleaned to remove adhering soil particles, air-dried, and weighed to determine mass loss.

The percentage weight loss (WL%) was calculated using the following equation:

$$WL(\%) = \frac{(W_i - W_t)}{W_i}\ x\ 100 \quad (2)$$

where W_i is the initial dry weight of the film sample, and W_t is the dry weight after the burial period. Biodegradation tests were conducted in biologically active soil obtained from an open field environment.

2.7. Light Transmission Properties of Films

Optical transparency was determined using a UV–Vis spectrophotometer (Shimadzu UV-1800, Japan). Film samples (2 × 2 cm) were analyzed at 200, 400, 600, and 800 nm, and the transmittance (T%) was calculated using the equation below.

$$T = 10^{-A} x\ 100 \quad (3)$$

where *A* denotes the absorbance at the specified wavelength.

In addition, the opacity of the films was determined at 600 nm using the following formula (29).

$$Opacity = \frac{A_{600}}{film\ thickness\ (mm)} \quad (4)$$

2.8. DPPH Radical Scavenging Activity of Films

Antioxidant activity of the films was determined using the DPPH radical scavenging method (30). Film samples (1 × 1 cm) were directly immersed in 0.1 mM DPPH solution prepared in methanol and incubated at 37 °C in the dark for 45 min to allow interaction between the film components and DPPH radicals. After incubation, the film samples were removed from the solution, and the absorbance of the remaining DPPH solution was measured at 517 nm using a UV–Vis spectrophotometer.

The radical scavenging activity (%) was calculated according to the following equation:

$$Scavenging\ activity\ (\%) = \frac{A_{control} - A_{sample}}{A_{control}}\ x\ 100 \quad (5)$$

where $A_{control}$ is the absorbance of the DPPH solution without the film sample, and A_{sample} is the absorbance in the presence of the film.

2.9. WVP of Films

WVP was measured using a modified gravimetric method (31). Glass bottles were dried at 120 °C to constant weight, filled with silica gel, and sealed with film samples to create an airtight system. The assemblies were placed in a controlled chamber at 25 ± 2 °C and 50 ± 5% relative humidity (RH). After 36 h, the bottles were weighed again, and WVP was calculated using the equation below:

$$WVP = \frac{\Delta_m x\ l}{A\ x\ t\ x\ \Delta P} \quad (6)$$

where Δ_m (g) is the mass of water passing through the film (calculated as the difference in mass before and after testing), l (mm) is the film thickness, A (mm^2) is the effective surface area of the film exposed to vapor, t (h) is the exposure time, and ΔP (Pa) is the water vapor pressure difference across the film.

2.10. Statistical Analysis

All experiments were performed in triplicate. The results are presented as mean ± standard deviation. Error bars in the figures represent the standard deviation of the measurements. Statistical analyses were performed using IBM SPSS Statistics version 19.0 (IBM Corp., Armonk, NY, USA). Statistical analysis was carried out using one-way analysis of variance (ANOVA) to evaluate differences between samples, followed by Tukey's multiple comparison test when significant differences were detected**.** A significance level of $p < 0.05$ was considered statistically significant.

3. RESULTS AND DISCUSSION

3.1. Swelling Behavior

Swelling behavior is an important parameter for evaluating water–polymer interactions and structural stability in hydrophilic film systems (32). Both gelatin and PVA possess polar functional groups that promote water absorption; however, the extent of swelling is determined not only by the chemical nature of the polymers but also by the organization and rigidity of the polymer network. As shown in Figure 1, the gelatin film exhibited a relatively high swelling ratio, which can be attributed to extensive chain relaxation and unrestricted expansion upon hydration. The hydrophilic nature of gelatin facilitates water diffusion into the polymer matrix, leading to a pronounced swelling behavior (33). Despite its hydrophilic character, the incorporation of PVA into the gelatin matrix led to a noticeable decrease in swelling ratio (34). This observation suggests that PVA acts primarily as a structural modifier rather than simply increasing water affinity. Enhanced intermolecular interactions between gelatin and PVA chains contribute to the formation of a more compact and constrained network, limiting chain mobility and reducing the free volume available for water diffusion. Consequently, the PVA/gelatin films absorb water in a more controlled manner and reach swelling equilibrium at lower values compared to pure gelatin films.

3.2. Thickness

Table 1 shows that film thickness was only slightly affected by polymer blending and lemon peel extract incorporation, whereas the presence of rosehip seed oil resulted in a pronounced increase in thickness. The gelatin film exhibited a thickness of 0.108 ± 0.0025 mm, while the PVA/gelatin film showed a comparable value of 0.112 ± 0.0022 mm. No statistically significant difference was observed between these two films ($p > 0.05$). Similarly, the incorporation of lemon peel extract produced only a slight increase in thickness (0.115 ± 0.0022 mm), although this value was significantly higher than that of the gelatin film ($p < 0.05$). In contrast, films containing rosehip seed oil exhibited markedly higher thickness values. The RSO-loaded PVA/gelatin film reached 0.235 ± 0.0027 mm, which further increased slightly to 0.243 ± 0.0026 mm in the LPE@RSO-loaded film. These two oil-containing films did not differ significantly from each other ($p > 0.05$), but both exhibited significantly greater thickness than the oil-free films ($p < 0.05$). This increase can be attributed to the presence of the oil phase within the polymer network, which likely interferes with the packing of polymer chains and increases the free volume of the matrix during film formation. These results indicate that film thickness is primarily influenced by the incorporation of RSO rather than by polymer blending or lemon peel extract addition. The oil-containing films exhibit a more expanded structure, reflected in their significantly higher thickness values compared to oil-free films (35, 36).

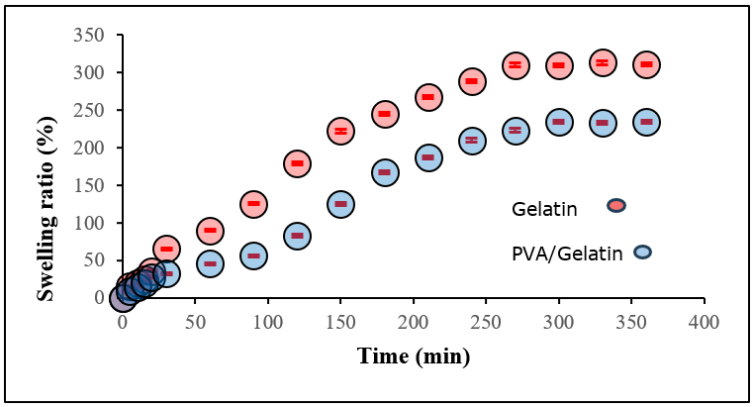


Figure 1: Swelling behavior of gelatin and PVA/gelatin films as a function of immersion time in distilled water at 24 ± 1. Values represent mean ± standard deviation (n = 3).

In the present study, the casting volume and drying conditions were kept constant for all film formulations. Therefore, the observed increase in thickness is mainly attributed to the incorporation of the oil phase rather than processing conditions. The presence of the oil phase may promote microstructural heterogeneity or partial phase separation within the polymer matrix, which can contribute to the formation of thicker films. A similar increase in film thickness after incorporation of essential oils has been reported for PVA–chitosan systems containing cinnamon essential oil (37).

3.3. Light Transmittance and Opacity

Light transmittance and opacity are key parameters for evaluating the protective capacity of packaging films against light-induced deterioration. As shown in Table 2, the optical properties of the films vary depending on polymer composition and the presence of natural additives. The gelatin film exhibited moderate visible light transmittance at 600 nm (72.40 ± 0.004 %) together with the highest opacity value (7.41), indicating limited transparency. This behavior is associated with the inherent heterogeneity of gelatin-based films, which promotes internal light scattering. In contrast, blending gelatin with PVA significantly improved optical clarity, as evidenced by the high transmittance at 600 nm (91.41 ± 0.0025 %) and the marked reduction in opacity (3.18). This suggests that PVA contributes to a more uniform film with fewer scattering sites. All PVA/gelatin-based films showed extremely low transmittance values at 200 nm, reflecting effective UV-barrier behavior. The near-zero UV transmittance observed for films containing lemon peel extract can be attributed to the presence of phenolic compounds, which strongly absorb UV radiation. Accordingly, the LPE-loaded PVA/gelatin film exhibited lower visible light transmittance (61.49 ± 0.00456 % at 600 nm) and higher opacity (4.90) compared to the additive-free blend. The incorporation of rosehip seed oil into the PVA/gelatin matrix resulted in a slight decrease in visible light transmittance (89.54 ± 0.0029 %) and a moderate increase in opacity (3.65), which may be related to the formation of dispersed oil domains within the film. When lemon peel extract and rosehip seed oil were combined, the film exhibited a further increase in opacity (5.12) and moderate visible light transmittance (68.78 ± 0.0160 %), indicating increased internal heterogeneity and enhanced light-blocking capacity. The incorporation of lemon peel extract and rosehip seed oil contributes to improved UV and visible light barrier properties, while maintaining sufficient transparency for food packaging applications where protection against light exposure is required.

Table 1: Thickness of gelatin, PVA/gelatin, and rosehip seed oil–loaded PVA/gelatin films measured at 24 ± 1 °C. Values are expressed as mean ± standard deviation (n = 3) in mm.

Film code	Thickness (mm)
Gelatin	0.108 ± 0.0025
PVA/Gelatin	0.112 ± 0.0022
LPE loaded-PVA/Gelatin	0.115± 0.0022
RSO loaded-PVA/Gelatin	0.235 ± 0.0027
LPE@RSO loaded-PVA/Gelatin	0.243± 0.0026

Table 2: Opacity and light transmittance (%) at 200, 400, and 600 nm of gelatin, PVA/gelatin, and PVA/gelatin films loaded with LPE and/or RSO, measured at 24 ± 1 °C. Values are expressed as mean ± standard deviation (n = 3).

Film code	Light transmittance (%)			Opacity
	200	400	600	
Gelatin	0.72 ±0,002	50.80 ± 0.006	72.40± 0.004	7.41
PVA/Gelatin	0.0002 ± 0,00330	57.1479 ± 0.00450	91.4113 ± 0.0025	3.18
RSO loaded-PVA/Gelatin	0.0001 ± 0,00340	56.1479 ± 0.00531	89.5365 ± 0.0029	3.65
LPE loaded-PVA/Gelatin	0.0003 ± 0.0002	52.5893 ± 0.00250	61.4927 ± 0.00456	4.90
LPE@RSO loaded-PVA/Gelatin	0.0002 ± 0.0002	57.8849 ± 0.00470	68.7761 ± 0.160	5.12

3.4. Biodegradability in soil

Soil burial tests provide valuable insight into the environmental fate of polymeric films under natural conditions. In the present study, the biodegradation behavior of gelatin and PVA/gelatin films was monitored over a 20-day period, with a conventional plastic film used as reference material. As illustrated in Figure 2, the control film showed no measurable mass loss throughout the test duration, confirming its resistance to microbial degradation.

In contrast, both gelatin-based films exhibited clear time-dependent degradation in soil, which was also visually evident in Figure 2. The gelatin film showed rapid degradation during the early stages, with approximately 29.7% mass loss observed by day 4 and more than 54% degradation by day 7. Degradation progressed further with prolonged burial, reaching nearly 88% by day 10 and complete degradation (100%) by day 20. This rapid degradation behavior can be attributed to the high moisture affinity of gelatin, which facilitates microbial colonization and enzymatic breakdown. The PVA/gelatin film followed a similar degradation pattern, but at a slower rate during the initial stages. Mass loss values of approximately 19.8% and 33.2% were recorded on days 4 and 7, respectively, indicating delayed degradation compared to the gelatin film. As shown in Figure 3, the PVA/gelatin film for a longer period, despite visible surface changes. However, extended soil exposure led to pronounced degradation, with mass loss increasing to 62.3% by day 10 and 76.5% by day 20. These results demonstrate that the incorporation of PVA does not prevent biodegradation, but moderates its progression. Compared with pure gelatin films, PVA/gelatin films exhibit improved short-term stability while still undergoing substantial degradation under soil conditions, which is advantageous for applications requiring controlled service life followed by environmental disintegration.

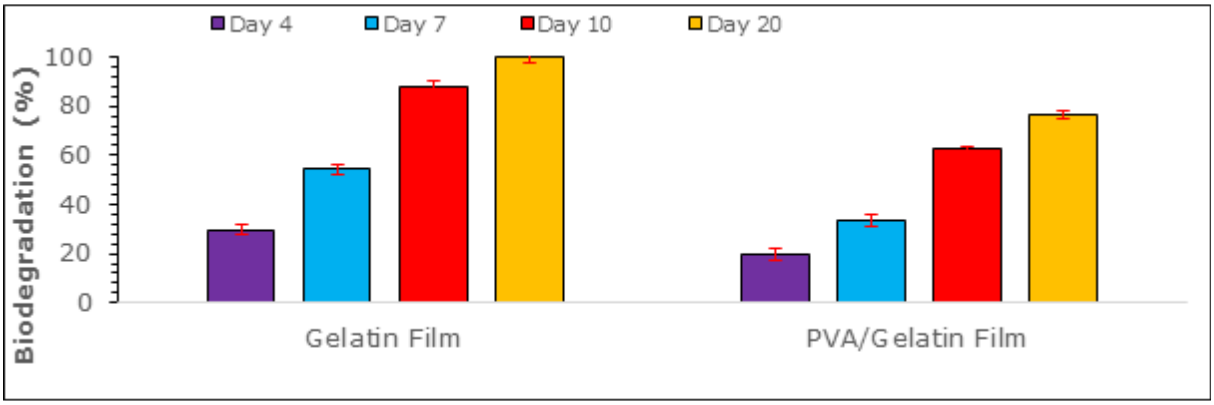


Figure 2: Biodegradation rates (%) of gelatin and PVA/gelatin films during soil burial at different time intervals (days 4, 7, 10, and 20) at 24 ± 1 °C. Values represent mean ± standard deviation (n = 3).

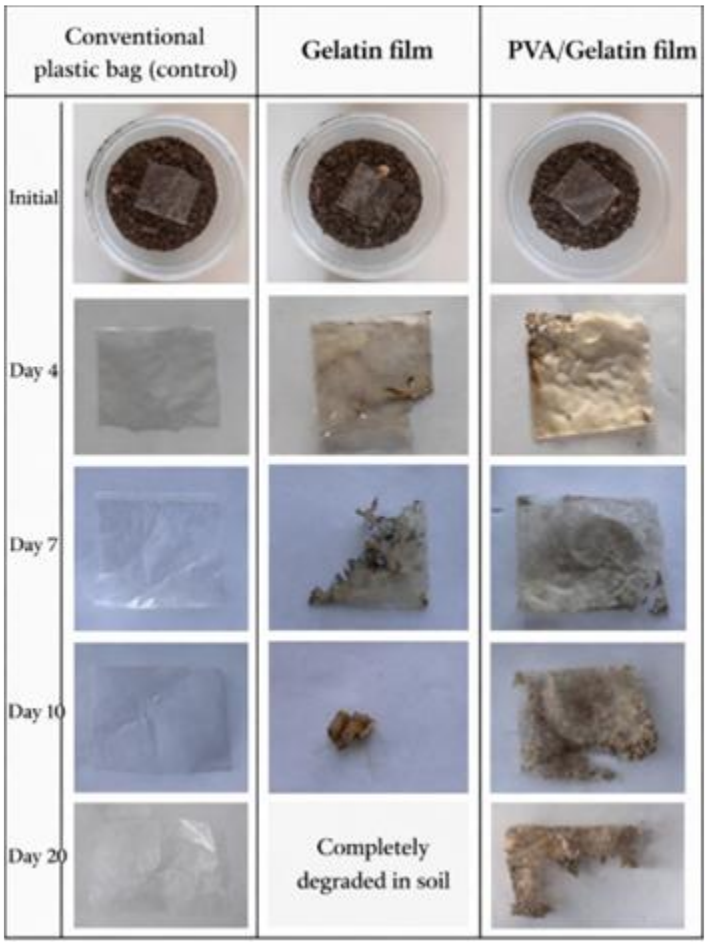


Figure 3: Progressive physical changes of gelatin and PVA/gelatin films observed during soil burial at different time intervals (0, 4, 7, 10, and 20 days).

3.5. Antioxidant Properties

The antioxidant activity of the films was evaluated using the DPPH radical scavenging assay, and the results demonstrate the influence of natural additives on radical scavenging capacity. As expected, the gelatin film exhibited low antioxidant activity, with a DPPH radical scavenging value of 9.66%, while the PVA/gelatin film showed a slightly higher value of 10.65%. As shown in Figure 4, these low values indicate that the polymer matrix itself contributes minimally to radical scavenging activity. When lemon peel extract was incorporated into the PVA/gelatin matrix, a substantial increase in antioxidant activity was observed, with the LPE-loaded PVA/gelatin film reaching 68.89% radical scavenging activity. This enhancement is likely related to the presence of phenolic compounds in lemon peel extract, which can act as hydrogen or electron donors capable of neutralizing free radicals. Similar observations have been reported for other

biopolymer film systems containing plant extracts. For instance, Hanani et al. reported that tapioca starch/gelatin films incorporating 5% *Garcinia atroviridis* leaves (GAL) exhibited a DPPH radical scavenging activity of 56.88%, which was associated with the phenolic compounds present in the extract (38). Rosehip seed oil also contributed to antioxidant activity, with the RSO-loaded PVA/gelatin film exhibiting a DPPH scavenging value of 74.67%. This effect may be related to the bioactive components present in rosehip seed oil, including unsaturated fatty acids and minor antioxidant constituents that contribute to free radical inhibition. The highest antioxidant activity (78.67%) was obtained for the LPE@RSO-loaded PVA/gelatin film, suggesting a synergistic effect between lemon peel extract and rosehip seed oil. The presence of both additives likely provides complementary antioxidant mechanisms within the polymer matrix, resulting in improved radical scavenging performance compared with films containing a single additive. A comparable antioxidant effect of essential oil incorporation in gelatin-based films was also reported by Ocak et al., where films containing *Origanum onites* essential oil reached 46.52% radical scavenging activity (39).

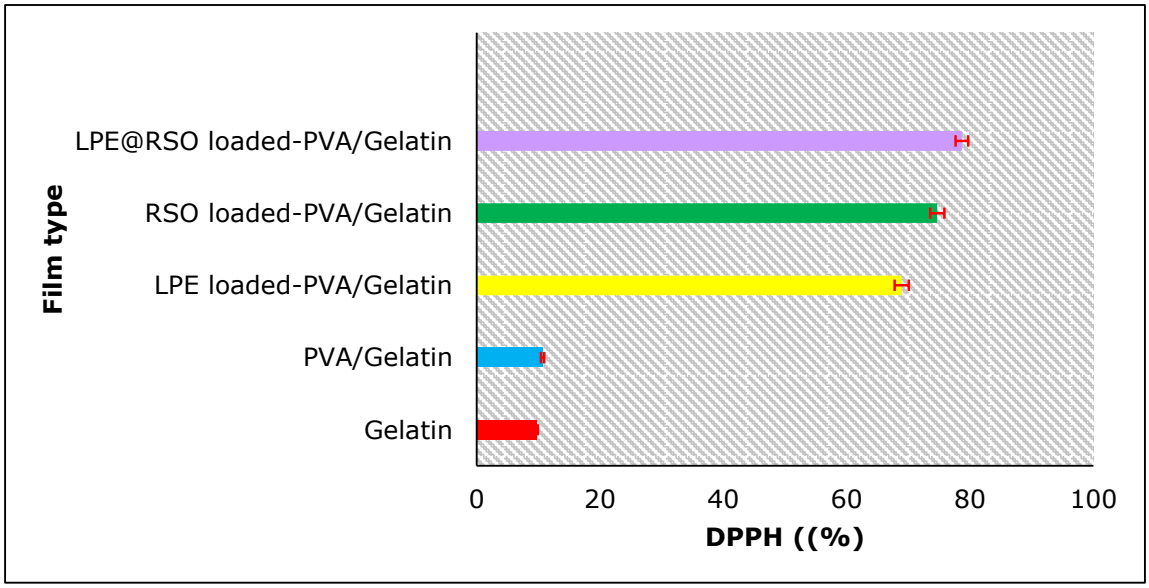


Figure 4: Radical scavenging activity (%) of gelatin, PVA/gelatin, and PVA/gelatin films containing LPE, RSO, and their combination (LPE@RSO) determined using the DPPH method. Values represent mean ± standard deviation (n = 3).

3.6. WVP of films

Water vapor permeability is a key indicator of the ability of packaging films to regulate moisture transfer, which directly affects food stability during storage. The WVP values obtained in this study demonstrate that film composition has a clear influence on moisture barrier performance. As shown in Figure 5, the gelatin film exhibited the highest WVP value (18.25×10^{-6} g·m^{-1}·s^{-1}·Pa^{-1}), indicating relatively unrestricted water vapor diffusion through the polymer matrix. Upon blending gelatin with PVA, a pronounced decrease in WVP was observed, with the PVA/gelatin film showing a value of 8.30×10^{-6} g·m^{-1}·s^{-1}·Pa^{-1}. This reduction suggests that polymer blending leads to a more compact internal structure, which limits moisture transport despite the hydrophilic nature of both polymers. Further incorporation of lemon peel extract resulted in an additional decrease in WVP to 7.45×10^{-6} g·m^{-1}·s^{-1}·Pa^{-1}. This behavior may be associated with interactions between polar compounds present in the extract and the polymer chains, contributing to improved matrix cohesion and reduced free volume for water vapor diffusion. The lowest WVP value (6.23×10^{-6} g·m^{-1}·s^{-1}·Pa^{-1}) was observed for the RSO-loaded PVA/gelatin film, which can be attributed to the formation of hydrophobic domains that partially interrupt water vapor diffusion pathways. When lemon peel extract and rosehip seed oil were incorporated together, the WVP remained low (6.34×10^{-6} g·m^{-1}·s^{-1}·Pa^{-1}), indicating that the combined additives maintained an effective moisture barrier without a significant increase in permeability (40–42).

These results are important for food packaging applications where controlling moisture transfer is necessary to maintain food quality during storage. Films with lower WVP values can help protect moisture-sensitive foods by limiting water vapor migration and slowing quality deterioration. Therefore, the improved barrier performance observed in the RSO-containing PVA/gelatin films suggests that these films may be suitable candidates for biodegradable food packaging applications.

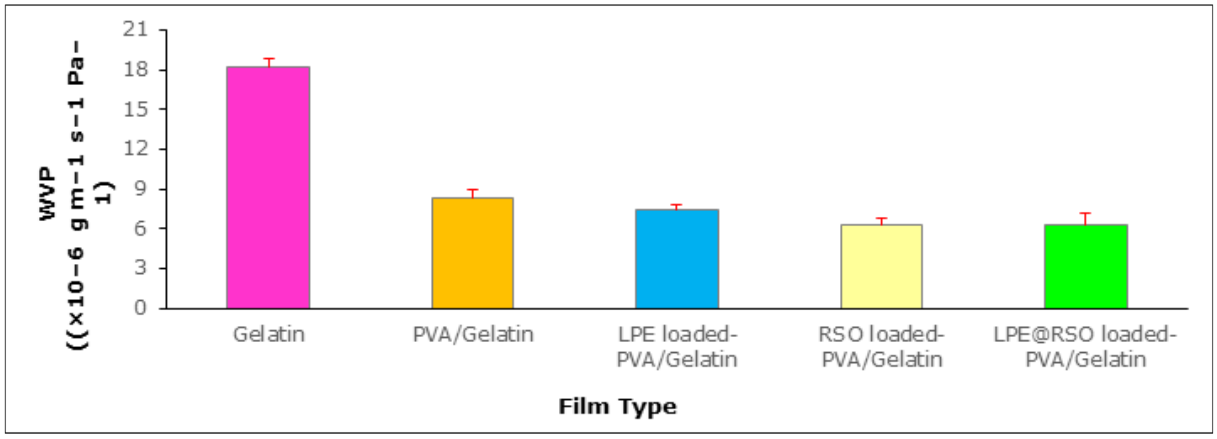


Figure 5: Water vapor permeability (WVP) of gelatin, PVA/gelatin, and PVA/gelatin films loaded with lemon peel extract and/or rosehip seed oil ($\times 10^{-6}$ g·m^{-1}·s^{-1}·Pa^{-1}), measured at 24 ± 1 °C. Values represent mean ± standard deviation (n = 3).

4. CONCLUSION

In this study, biodegradable films based on gelatin and PVA/gelatin blends were successfully prepared and functionalized with lemon peel extract and rosehip seed oil. The effects of polymer blending and natural additives on swelling behavior, optical properties, antioxidant activity, water vapor permeability, and soil biodegradation were systematically evaluated. Blending gelatin with PVA resulted in films with reduced swelling, lower water vapor permeability, and a more controlled biodegradation rate compared with pure gelatin films. This indicates that PVA contributes to improved structural stability while maintaining biodegradability. The incorporation of lemon peel extract significantly enhanced the antioxidant activity of the films and increased their light barrier properties, reflecting the contribution of phenolic compounds present in the extract. Rosehip seed oil further improved moisture barrier performance by reducing water vapor permeability, likely due to the formation of hydrophobic domains within the polymer matrix. Soil burial tests demonstrated that both gelatin and PVA/gelatin films undergo substantial degradation under natural conditions, while PVA incorporation moderated the degradation rate and prolonged structural integrity. Among the developed formulations, the PVA/gelatin film containing both lemon peel extract and rosehip seed oil (LPE@RSO) exhibited the highest antioxidant activity while maintaining low water vapor permeability, indicating a synergistic contribution of the two natural additives to both functional and barrier properties. The results suggest that PVA/gelatin films incorporating natural additives derived from agricultural by-products represent promising candidates for sustainable food packaging applications, offering an effective combination of biodegradability and functional properties. In particular, the LPE@RSO formulation may be suitable for packaging moisture-sensitive foods where antioxidant protection is desirable. Future studies may focus on evaluating antimicrobial properties, mechanical stability, and performance under real food storage conditions.

5. CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

6. ACKNOWLEDGMENTS

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7. REFERENCES

1. Ncube LK, Ude AU, Ogunmuyiwa EN, Zulkifli R, Beas IN. Environmental impact of food packaging materials: A review of contemporary development from conventional plastics to polylactic acid based materials. Materials. 2020;13(21):4994. **<DOI>**.

2. Mendes AC, Pedersen GA. Perspectives on sustainable food packaging: Is bio-based plastics a solution? Trends Food Sci Technol. 2021;112:839–846. **<DOI>.**

3. Qasim U, Osman AI, Al-Muhtaseb AAH, Farrell C, Al-Abri M, Ali M, Rooney DW. Renewable cellulosic nanocomposites for food packaging to avoid fossil fuel plastic pollution: A review. Environ Chem Lett. 2021;19(1):613–641. **<DOI>**.

4. Manikandan G, Senthilkumar G, Chen CW, Nagarajan D, Chang JS, Dong CD. Valorization of brown seaweed into next-generation alginate bioplastic films: Functional enhancements and smart packaging applications. Carbohydr Polym. 2025;124356. **<DOI>**.

5. Ali A, Ahmed S. Eco-friendly natural extract loaded antioxidative chitosan/polyvinyl alcohol based active films for food packaging. Heliyon. 2021;7(3):e06550. **<DOI>**.

6. Taktak FF, Kaya HN. Biodegradable PVA/chitosan-based films enriched with rose hip extract and seed oil: Influence of tragacanth gum ratio on functional properties and application in cherry preservation. Int J Biol Macromol. 2025;307:141023. **<DOI>**.

7. Taktak FF, Kaya HN. Enhanced antibacterial activity and biodegradability of PVA/chitosan/gum tragacanth films enriched with ZnO and safflower oil. J Macromol Sci B. 2025;1–24. **<DOI>**.

8. Dallaev R, Papež N, Allaham MM, Holcman V. Biodegradable polymers: Properties, applications, and environmental impact. Polymers. 2025;17(14):1981. **<DOI>**.

9. Iyyappan J, Dhivya S, Banupriya P, Nithisha B. Development of sustainable biodegradable thin films from blended natural extracts and biopolymers for commercial food packaging. Food Humanity. 2025;100926. **<DOI>**.

10. Kurabetta LK, Masti SP, Gunaki MN, Hunashyal AA, Chougale RB, Dalbanjan NP, Kumar SP. Vanillin reinforced cationic starch/poly(vinyl alcohol) based antimicrobial and antioxidant bioactive films. Sustain Food Technol. 2025;3(5):1353–1364. **<DOI>**.

11. Deng H, Su J, Zhang W, Khan A, Sani MA, Goksen G, Rhim JW. A review of starch/polyvinyl alcohol (PVA) blend films as a potential replacement for traditional plastic-based food packaging materials. Int J Biol Macromol. 2024;273:132926. **<DOI>**.

12. Dubey P, Tripathi G, Mir SS, Yousuf O. Current scenario and global perspectives of citrus fruit waste as a valuable resource for the development of food packaging films. Trends Food Sci Technol. 2023;141:104190. **<DOI>**.

13. García-González AG, Rivas-García P, Escamilla-Alvarado C, Ramírez-Cabrera MA, Paniagua-Vega D, Galván-Arzola U, Escárcega-González CE. Fruit and vegetable waste as a raw material for obtaining functional antioxidants and their applications: A review of a sustainable strategy. Biofuels Bioprod Biorefin. 2025;19(1):231–249. **<DOI>.**

14. Akachat B, Himed L, Salah M, D'Elia M, Rastrelli L, Barkat M. Development of pectin-based films with encapsulated lemon essential oil for active food packaging: Improved antioxidant activity and biodegradation. Foods. 2025;14(3):353. **<DOI>**.

15. Selvaraj RCA, Kanagaraj A, Karuppiah P, Ravindran S, Raj MM, Senthamaraikannan P, Suyambulingam I. Leveraging citrus extract to enhance antioxidant properties of mung bean (*Vigna radiata*) protein edible films. Biomass Convers Biorefin. 2025;1–16. **<DOI**>.

16. Han S, Ansari JR, Park K, Sadeghi K, Seo J. Carbon quantum dots synthesized from lemon extract to enhance the performance of polylactic acid films for packaging applications. J Ind Eng Chem. 2025. **<DOI**>.

17. Mathew D, Thomas B, Sudheep NM, Shamil KM, Anjana R, Krishna A, Krishnankutty RE. Development of garlic extract-loaded zinc oxide nanoparticle/chitosan/polyvinyl alcohol nanocomposite-based active packaging films for extending shelf life of fish fillets. Int J Biol Macromol. 2025;147273. **<DOI>**.

18. Koirala P, Sablani SS, Nirmal N. Gelatin/pectin-based composite films reinforced with mango peel extract-loaded zein nanoparticles and zinc oxide nanoparticles. LWT. 2025;117997. **<DOI>**.

19. de Almeida Canoff JR, Donadel G, Dalmagro M, Pinc MM, Sone AP, Macruz PD, Hoscheid J. Polymeric film loaded with *Plinia cauliflora* peel extract and its curative effect on injuries. J Pharm Innov. 2025;20(1):23. **<DOI>**.

20. Sun Y, Jia S, Hou Y, Cheng S, Tan M, Zhu B, Wang H. Novel thyme essential oil-loaded biodegradable emulsion film based on soybean lipophilic proteins for salmon preservation. Food Hydrocoll. 2025;160:110790. **<DOI>**.

21. Shao Z, Lan W, Xie J. A konjac glucomannan/gelatin film integrated with rosemary essential oil and ginger essential oil-loaded bacterial cellulose: Preparation, characterization, and application in sea bass (*Lateolabrax maculatus*) packaging. Food Chem. 2025;478:143604. **<DOI>**.

22. Zhang S, Ma Y, Wang X, Zhou X, Fang Y, Shen W, Ge X. Preparation of cinnamon essential oil-micelles/blueberry anthocyanins-loaded PVA bifunctional electrospinning nanofibrous film for maintaining and monitoring shrimp

freshness. Food Chem. 2025;145795. **<DOI>**.

23. Fan L, Yang H, Yang J, Peng M, Hu J. Preparation and characterization of chitosan/gelatin/PVA hydrogel for wound dressings. Carbohydr Polym. 2016;146:427–434. **<DOI>**.

24. Gürler N. Development of chitosan/gelatin/starch composite edible films incorporated with pineapple peel extract and aloe vera gel: Mechanical, physical, antibacterial, antioxidant, and sensorial analysis. Polym Eng Sci. 2023;63(2):426–440. **<DOI>.**

25. Khah MD, Ghanbarzadeh B, Roufegarinejad-Nezhad L, Ostadrahimi A. Effects of virgin olive oil and grape seed oil on physicochemical and antimicrobial properties of pectin–gelatin blend emulsified films. Int J Biol Macromol. 2021;171:262–274. **<DOI>.**

26. Khah MD, Ghanbarzadeh B, Roufegarinejad-Nezhad L, Ostadrahimi A. Effects of virgin olive oil and grape seed oil on physicochemical and antimicrobial properties of pectin–gelatin blend emulsified films. Int J Biol Macromol. 2021;171:262–274. **<DOI>.**

27. Shahbazi Y. The properties of chitosan and gelatin films incorporated with ethanolic red grape seed extract and *Ziziphora clinopodioides* essential oil as biodegradable materials for active food packaging. Int J Biol Macromol. 2017;99:746–753. **<DOI>.**

28. Taktak F, Gökçe S. Ultrasound-assisted synthesis of biodegradable graphene oxide-based hydrogel nanocomposites for highly efficient and cost-effective removal of methyl orange from aqueous media. J Water Process Eng. 2024;58:104837. **<DOI>**.

29. Wang L, Fu H, Tan Q, Wu S, Wang Y, Peng X. Preservation effects of chitosan/polyvinyl alcohol/clove essential oil antifungal film on yellow peaches: Physicochemical properties and fruit quality assessment. Food Control. 2024;164:110582. **<DOI>**.

30. Guzman-Puyol S, Benítez JJ, Heredia-Guerrero JA. Transparency of polymeric food packaging materials. Food Res Int. 2022;161:111792. **<DOI>**.

31. Vázquez B, San Roman J, Peniche C, Cohen ME. Polymeric hydrophilic hydrogels with flexible hydrophobic chains: Control of hydration and interactions with water molecules. Macromolecules. 1997;30(26):8440–8446. **<DOI>.**

32. Gil ES, Frankowski DJ, Spontak RJ, Hudson SM. Swelling behavior and morphological evolution of mixed gelatin/silk fibroin hydrogels. Biomacromolecules. 2005;6(6):3079–3087. **<DOI>**.

33. Li CS, Xu Y, Li J, Qin SH, Huang SW, Chen XM, Xiao JH. Ultramodern natural and synthetic polymer hydrogel scaffolds for articular cartilage repair and regeneration. Biomed Eng Online. 2025;24(1):1–26. **<DOI>**.

34. Chen J, Zheng M, Tan KB, Lin J, Chen M, Zhu Y. Polyvinyl alcohol/xanthan gum composite film with excellent food packaging, storage, and biodegradation capability as a potential environmentally friendly alternative to commercial plastic bags. Int J Biol Macromol. 2022;212:402–411. **<DOI>**.

35. Mirsharifi SM, Sami M, Jazaeri M, Rezaei A. Production, characterization, and antimicrobial activity of almond gum/polyvinyl alcohol/chitosan composite films containing thyme essential oil nanoemulsion for extending the shelf life of chicken breast fillets. Int J Biol Macromol. 2023;227:405–415**. <DOI**>.

36. Wang D, Shao S, Wang B, Guo D, Tan L, Chen Q. Fabrication of chitosan/guar gum/polyvinyl alcohol films incorporated with polymethoxyflavone-rich citrus extracts: Post-harvest shelf-life extension of strawberry fruits. Prog Org Coat. 2024;194:108611. **<DOI**>.

37. Zhang M, Wang L, Zou X, Song R. Electrospun film polyvinyl alcohol/chitosan loaded with cinnamon essential oil and inhibitory effects on polyphenol oxidase and dominant spoilage bacteria from Pacific white shrimp. Food Hydrocoll. 2024;156:110372. <**DOI> .**

38. Najwa INA, Guerrero P, De La Caba K, Hanani ZN. Physical and antioxidant properties of starch/gelatin films incorporated with Garcinia atroviridis leaves. Food Packag Shelf Life. 2020;26:100583. **<DOI>.**

39. Kılınç D, Ocak B, Özdestan-Ocak Ö. Preparation, characterization and antioxidant properties of gelatin films incorporated with *Origanum onites* L. essential oil. J Food Meas Charact. 2021;15(1):795–806. **<DOI>.**

40. Radoor S, Jayakumar A, Karayil J, Kim JT, Siengchin S. *Nelumbo nucifera* flower extract incorporated alginate/polyvinyl alcohol films as a sustainable pH indicator

for active food packaging applications. Int J Biol Macromol. 2024;273:133170. **<DOI**>.

41. Azadi A, Rafieian F, Sami M, Rezaei A. Fabrication, characterization and antimicrobial activity of chitosan/tragacanth gum/polyvinyl alcohol composite films incorporated with cinnamon essential oil nanoemulsion. Int J Biol Macromol. 2023;245:125225. **<DOI>**.

42. Shen L, Chen C, Xie J. Development and characterization of starch/polyvinyl alcohol active films with slow-release property by utilizing *Mucor racemosus* mycelium to load clove essential oil. Int J Biol Macromol. 2025;295:139610. **<DOI**>.