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Research Article

Banana Peel Biofiller Loaded Polyvinyl Alcohol/Gelatin Ecofriendly Films

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Abstract

In view of sustainability goals, there is increased interest in evaluating biodegradable polymers and natural wastes for material development. In this context, biocomposites of polyvinyl alcohol (PVA) and gelatin incorporated with banana peel powder were fabricated by the solution-casting method. The influence of varying banana peel loadings (0.50–2.00 % wt. based on the total weight of polymer) on the color, morphology, mechanical, structural, thermal, and wettability features of the resultant PVA/gelatin biocomposite films was evaluated. The structural and morphological changes of the biocomposite films were characterized using Fourier transform infrared (FTIR) and scanning electron microscopy (SEM), while the thermal behavior of the films was determined using thermogravimetric analysis (TGA). SEM confirmed the increase in uniformity of surface morphology with the addition of banana peel. The tensile strength of the biocomposite films improved from 7.15±0.5 to 7.78±0.2 MPa with an increase in the banana peel concentration to 1% (wt). The incorporation of banana peel in the biocomposite films consequently increased their hydrophobicity. Similar thermal stability was observed in all biocomposite films. PVA/gelatin/banana peel biocomposite films have the potential to be on-the-go food wrappers and environmentally friendly food packaging that can contribute to a sustainable future.

Keywords: Biodegradable film, food package, sustainable materials, tensile properties.

Muz Kabuğu Biyodolgu Katkılı Polivinil Alkol/Jelatin Çevre Dostu Filmler

Öz

Sürdürülebilirlik hedefleri göz önüne alındığında, malzeme geliştirme için biyolojik olarak parçalanabilir polimerlerin ve doğal atıkların değerlendirilmesine olan ilgi artmaktadır. Bu bağlamda, muz kabuğu tozu ile birleştirilmiş polivinil alkol (PVA) ve jelatin biyokompozitleri çözelti döküm yöntemi ile üretilmiştir. Değişen muz kabuğu konsantrasyonlarının (ağırlıkça %0,50-2,00) elde edilen PVA/jelatin biyokompozit filmlerin renk, morgoloji, mekanik, yapısal, termal ve ıslanabilirlik özellikleri üzerindeki etkisi değerlendirilmiştir. Biyokompozit filmlerin yapısal ve morfolojik değişimleri Fourier dönüşümlü kızılötesi (FTIR) ve taramalı elektron mikroskobu (SEM) kullanılarak karakterize edilirken, filmlerin termal davranışı termogravimetrik analiz (TGA) kullanılarak belirlenmiştir. SEM analizi, muz kabuğunun eklenmesiyle yüzey morfolojisinin düzgünlüğünün arttığını doğrulamıştır. Muz kabuğu konsantrasyonunun %1'e artmasıyla biyokompozit filmlerin çekme dayanımı 7,15±0,5'ten 7,78±0,2 MPa'ya yükselmiştir. Biyokompozit filmlere muz kabuğunun dahil edilmesi, sonuç olarak hidrofobikliklerini artırmıştır. Tüm biyokompozit filmlerde benzer termal kararlılık gözlenmiştir. PVA/jelatin/muz kabuğu biyokompozit filmleri, sürdürülebilir bir geleceğe katkıda bulunabilecek, taşınabilir ve çevre dostu gıda ambalajları olma potansiyeli taşımaktadır.

Anahtar Kelimeler: Biyobozunur film, gıda ambalajı, sürdürülebilir malzemeler, çekme özellikleri.

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1. Introduction

The global production and utilization of plastics have experienced a significant surge over the past few decades. Various countries around the world, particularly European countries, are putting forward the use of biobased, biodegradable, and compostable polymers in every plastic product due to sustainability and cleaner production goals. Therefore, there is an intensified interest among researchers and industries to develop more sustainable alternatives to traditional plastics [1]. Investing in eco-friendly polymers and composites can help us transition towards a more circular economy and mitigate the harmful effects of plastic pollution on the environment [2].

Biodegradable materials are substances capable of undergoing degradation through the enzymatic activity of living organisms, including bacteria, yeasts, and fungi. Polyvinyl alcohol (PVA) is one of the extensively used biodegradable polymer with good chemical resistance and physical properties [3,4]. Recently, it was documented that a total of 55 species of microorganisms, including bacteria, molds, and yeast, are involved in the biodegradation process of PVA [5]. This hydroxyl-rich synthetic polymer is also biocompatible, non-toxic, transparent, and water-soluble [6,7]. Nowadays, PVA-based materials find extensive application across multiple fields such as adsorption, biomedical applications, cling film, food, and pharmaceutical packaging [7,8]. It is required to modify PVA for many applications. Hence, in order to improve the performance and environmental features of PVA, it is frequently blended with natural polymers and/or biobased reinforcements [6]. Among natural polymers, gelatin is highly miscible and compatible with PVA based on the presence of multifunctional groups in the backbone of each polymer [9]. On the other hand, gelatin is also an important biopolymer that has been generally evaluated to develop composite films related to the advantages of the biocompatible, biodegradable, colorless, tasteless, and film-forming capability [10,11].

The incorporation of filler reinforcement into biodegradable polymers gained prominence to create biocomposites. In recent years, food processing by-products have received significant attention due to their environmental benefits, low price, and renewable origin [3, 12-15]. They are also highly environmentally friendly byproducts utilized to develop extra biodegradable composite materials. As one of the most valuable by-products of the food industry, banana peel is a promising natural filler candidate for the fabrication of polymer-based composites [16]. During the production of banana chips, banana flour, baby foods, and unripe banana biomass, banana peel comes out, which is approximately 30-50 % of the banana fruit [17-19]. It is rarely evaluated as organic fertilizer and animal feed; however, the peels are widely left in the environment without any treatment [19]. Therefore, the conversion of banana peel as a biofiller will overcome the adverse environmental effects and economic losses. Recently, some studies focused on the evaluation of banana peel for packaging applications. Kumar et al. [20] reported the enhancements in properties of banana peel powder-loaded cellulose films with a banana peel powder ratio changing from 5wt.% to 25wt.% of cellulose. Fadeyibi et al. [21] also reported the nanocomposite packaging preparation based on banana peel and cocoyam starch for locust beans. According to Nida et al. [22], it is possible to develop banana peel/sugarcane bagasse packages using an extrusion-based 3D printing method. Available literature has shown that banana peels are suitable raw materials to prepare biodegradable and active packaging materials, which will bring a value addition to the biocircular economy.

However, despite these promising developments, there remains a clear research gap. Most existing studies rely on single-polymer matrices, and there is limited understanding of how banana peel interacts within multi-polymer networks, particularly combinations that can synergistically enhance mechanical, thermal, and barrier properties. Moreover, no study to date has examined biocomposites produced from the combined matrix of PVA and gelatin reinforced with banana peel powder.

In this context, the present study introduces a novel, environmentally friendly biocomposite film based on a PVA–gelatin blend reinforced with banana peel powder. PVA provides excellent film-forming ability and mechanical strength, while gelatin contributes biodegradability and flexibility; integrating banana peel powder is expected to further enhance the film's functionality. This unique combination has not been previously reported in the literature. The impact of varying levels of banana peel powder on the color, morphology, mechanical properties, structure, thermal characteristics, and wettability of the biocomposites was analyzed and assessed. By addressing the unexplored synergy between PVA, gelatin, and banana peel, this work offers a novel approach for upcycling agricultural waste into value-added packaging materials.

2. Material and Methods

2.1 Materials

Poly (vinyl alcohol) with a degree of hydrolysis of 87.2%, purity of 95.4%, was supplied by Zag Kimya (İstanbul, Türkiye). Gelatin from bovine skin (200-220 Bloom, type B) was purchased from Bursa Gelatin Food (Bursa, Türkiye). Banana was purchased from a local market (Bursa, Türkiye). The banana peel was dried in the oven at 70 °C and then ground into powder. Further, a steel mesh sieve was used to sieve banana peel (<100 µm). Glycerol was supplied by Merck (Darmstadt, Germany).

2.2 Film production

The solution casting method was used to develop PVA/gelatin based biocomposite films. Table 1 presents the amounts of materials used to prepare the biocomposite films. First, the PVA was dissolved in distilled water by magnetic stirring at 90 °C for 12 hours. Separately, gelatin was dissolved in distilled water by magnetic stirring at 60 °C for 1 hour. Both PVA and gelatin solutions were mixed and stirred at 60 °C for 1 hour to obtain a clear and homogeneous film-forming solution. Further, glycerol was added as a plasticizer. The solution was stirred for an additional 15 minutes at room temperature. Following this, banana peel powder was incorporated into the film-forming solution of PVA/gelatin at concentrations of 0.5%, 1.0%, 1.5%, and 2.0% (wt.% relative to the total mass of the polymers) and stirred for half an hour. The prepared solution (40 mL) was poured on the round glass petri dishes (14 cm x14 cm), then dried at room conditions (23 ±2 °C, 50 ± 5 % relative humidity) for 2 days. The dried films were peeled off from the petri dishes and stored in plastic bags in the desiccators until analysis. The biocomposite films were labeled as PGB-1, PGB-2, PGB-3, PGB-4, and PGB-5 with increasing banana peel content, respectively (Table 1).

Table 1. The initial composition of biocomposite film forming solution.

Sample Code	PVA (g/100 mL)	Gelatin (g/100 mL)	Banana peel (wt % of total polymer)	Glycerol (mL)
PGB-1	8	8	0	1
PGB-2	8	8	0.5	1
PGB-3	8	8	1.00	1
PGB-4	8	8	1.50	1
PGB-5	8	8	2.00	1

2.3 Structural characterization

Fourier transform infrared (FT-IR) spectra of the prepared films were carried out in the wavenumber range of 4000–500 cm^{-1} using a Nicolet iS50 FT-IR spectrometer (Thermo Fisher Scientific Co., Waltham, MA, USA). A small piece of biocomposite film was placed directly on the sample holder and scanned at a resolution of 4 cm^{-1}.

2.4 Scanning electron microscopy (SEM)

Surface morphologies and cross-sectional analyses of the films were conducted using a scanning electron microscope (Carl Zeiss/Gemini 300, Germany) at ×200 and ×100 magnification, respectively. The films were coated with a thin layer of gold (15 nm).

2.5 Color properties

The color parameters as L* (lightness), a* (red/green), b* (blue/yellow) of films were assessed using a spectrophotometer (X-Rite Ci7800, Michigan, USA) under the CIE Standard Illuminant D65 and 10 mm diameter area of illumination. The instrument was calibrated using a white standard and black trap included in the cap, and measurements were recorded in the CIE Lab* format. The yellowness index, whiteness index and total color difference (ΔE) were calculated using Eq. 1, Eq.2, and Eq.3 respectively [3].

$$\text{Yellowness Index} = 142.86 \frac{b^*}{L^*} \quad (1)$$

$$\text{Whiteness index} = 100 - \sqrt{(100 - L^*)^2 + a^{*2} + b^{*2}} \quad (2)$$

$$\Delta E = \sqrt{(L^* - L^*_{ref})^2 + (a^* - a^*_{ref})^2 + (b^* - b^*_{ref})^2} \quad (3)$$

2.6 Water contact angle (WCA) measurements

The contact angle of films was measured using an Attension Theta optical tensiometer (Biolin Scientific, Gothenburg, Sweden). The contact angle was measured three times with a water droplet volume of 5 μL. The average value was given as the final contact angle value.

2.7 Thickness

A digital caliper (ABS ASİMETO, Türkiye) was used to measure the thickness of the films. Measurements were performed at 5 random locations on each film. The average values were given as the result.

2.8 Mechanical properties

Mechanical properties of films were determined according to ASTM D882 using an AGS-X Series universal testing machine (Shimadzu, Japan). Prior to analysis, the films were conditioned at 23 ± 2 °C and 50 ± 5% relative humidity for 48 h. Each film was then cut into strips measuring 1 cm × 5 cm using a sharp steel blade to ensure clean and uniform edges. The analysis was performed with a load cell of 1 kN and a crosshead speed of 15 mm/min. Tensile parameters, including tensile strength and elongation at break, were presented as the average data with standard deviations that were calculated from five separate measurements of each film.

2.9 Thermal properties

Thermal properties of films were examined utilizing a TA/SDT650 thermogravimetric analyzer (TA Instruments, New Castle, USA). The films were heated with a heating rate of 20°C/min from 25°C to 600°C under a nitrogen atmosphere, followed by an oxygen atmosphere from 600°C to 900°C.

3. Results and Discussion

3.1 FT-IR spectroscopy results of banana peel and biocomposite films

The FTIR spectrum of banana peel is illustrated in Fig.1. It was quite similar to the spectrum reported by Afolabi et al. [23]. The band centered at 3299 cm^{-1} is related to the -OH group. The peaks at 2916 and 2850 cm^{-1} are ascribed to C-H stretching vibrations. The peak at 1736 cm^{-1} indicates the symmetrical stretching vibration of C=O of carboxylic acids and ketones. The sharp peak at 1592 cm^{-1} is assigned to the stretching vibration of amine bending. The bands at 1374 and 1315 cm^{-1} are attributed to the presence of cellulose [24]. The peaks at 1021 and 815 cm^{-1} are the stretching vibrations of C-OH and C-H, respectively [23].

The FTIR spectrum of PVA/gelatin and PVA/gelatin/banana peel biocomposite films with 0.5, 1.0, 1.5, and 2.0 wt% of banana peel loading are shown in Fig. 1. The spectrum of neat PVA/gelatin film (PGB-1) has peaks at 3290 and 2937 cm^{-1} are due to the stretching vibration of O-H and C-H, respectively [25]. The peak at 1730 and 1551 cm^{-1} indicates C=O stretching vibration of amide-I band [26] and amide II band [27], respectively. The peaks at 1424 and 1239 cm^{-1} corresponds to the stretching vibration of O-H bending and the C-O-C band, respectively [28]. The bending vibration of $CH-CH_2$ and C-O stretching was at 1088 cm^{-1} [29]. The peaks in the area between 1200 and 844 cm^{-1} present expansion of C=C and C=O [5]. Comparison of the spectra of the PVA/gelatin film and the banana peel incorporated films showed that the incorporation of banana peel to the PVA/gelatin matrix resulted in some changes in the intensity of the peaks without changing the frequency regions. The intensity changes were minor in films containing banana peel up to 1.5 wt.% due to the low loading concentrations. The intensity of the peaks at 2852 and 1030 cm^{-1} of PVA/gelatin film increased after 2.0 wt.% banana peel incorporation.

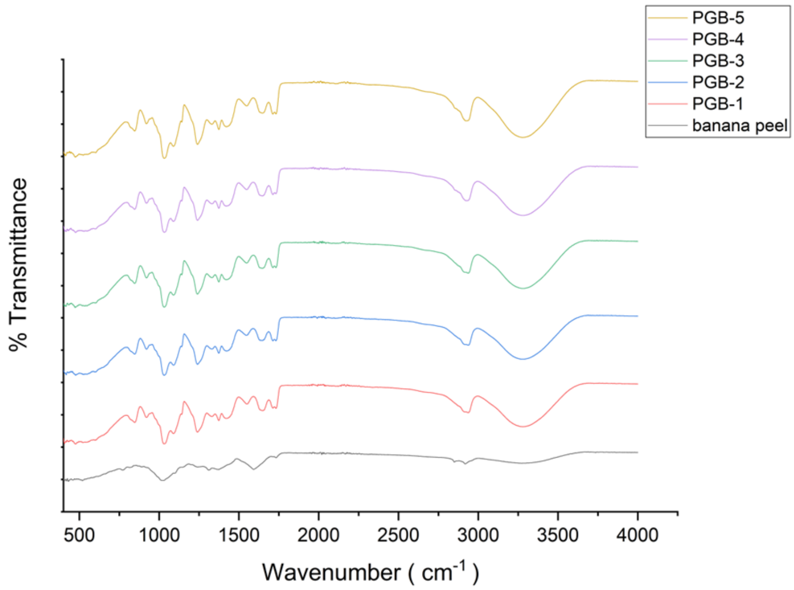


Figure 1. FTIR spectrum of banana peel and peel incorporated PVA/gelatin biocomposite films.

3.2 Morphological properties of banana peel and biocomposite films

The SEM micrograph of banana peel powder is presented in Fig.2. The SEM image evidently shows that the peel has irregular surface morphology with rough texture. The peel particles were heterogeneous in size. A similar result was also reported by Balavairavan and Saravanakumar for green banana peel powder [30].

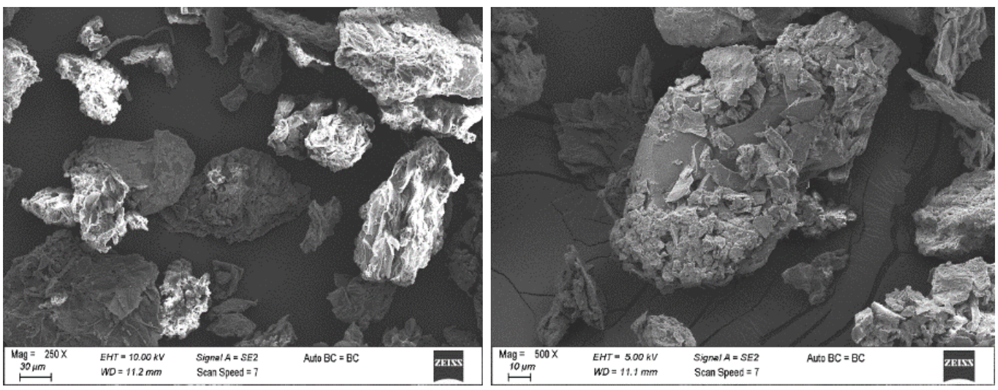
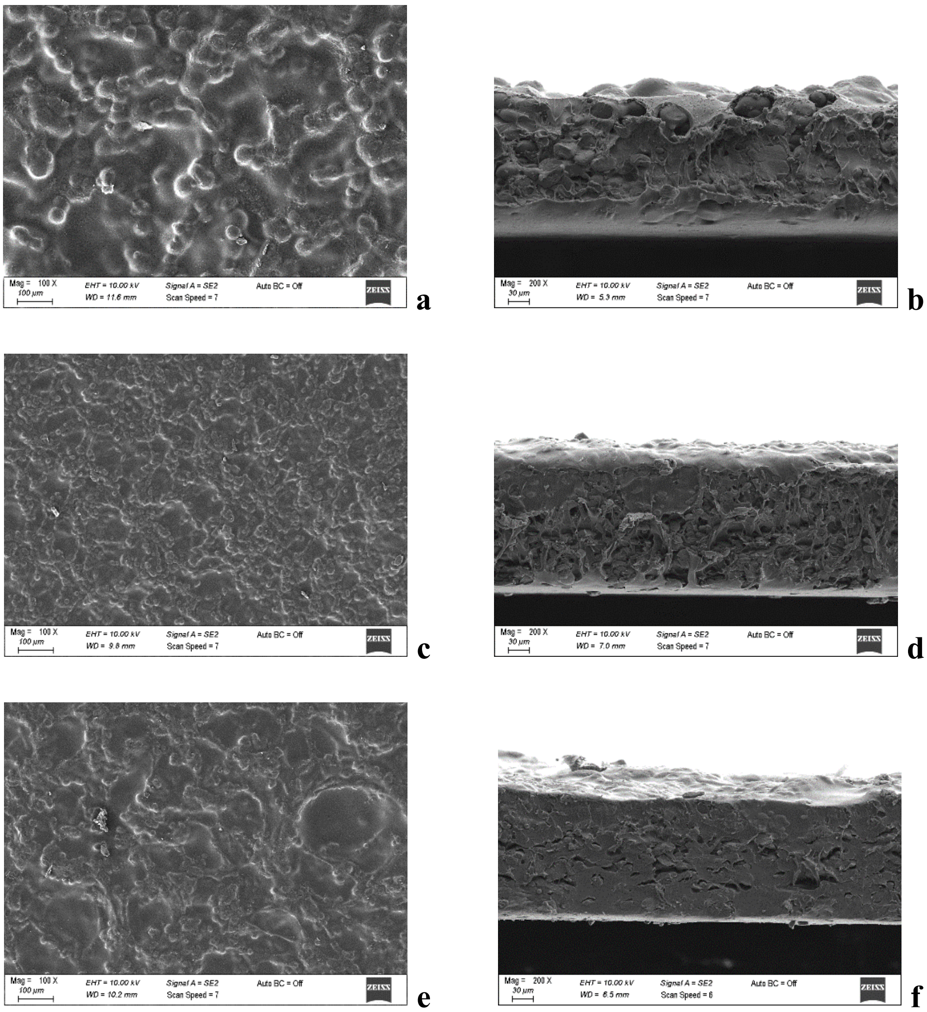


Figure 2. SEM images of the banana peel powders (a) 250x (b) 500x.

The cross-sectional and surface morphologies of the PVA/gelatin biocomposite films containing different amounts of banana peel powder are shown in Fig.3 (a-j). All films exhibited rough surfaces with structures that protruded from the air-side surface of the film. The mountain-like protrusions were also clearly observed in the cross-sectional view of the neat film (Fig.3b). There were no pores in the surface of the films. Similar to our results, Damayanti et al. [31] reported a similar surface view for PVA/gelatin films. The surface of the neat film became smoother with banana peel addition. Banana peel increased the compatibility of PVA and gelatin. In the cross-section of the neat film, an irregular structure without phase separation was observed indicating compatibility of polymers [9]. The cross-section of all biocomposite films exhibited heterogeneous structure with pores. As shown in Fig. 3f, cross-section of PGB-3 film became smoother.

Surface View **Cross-Sectional View**



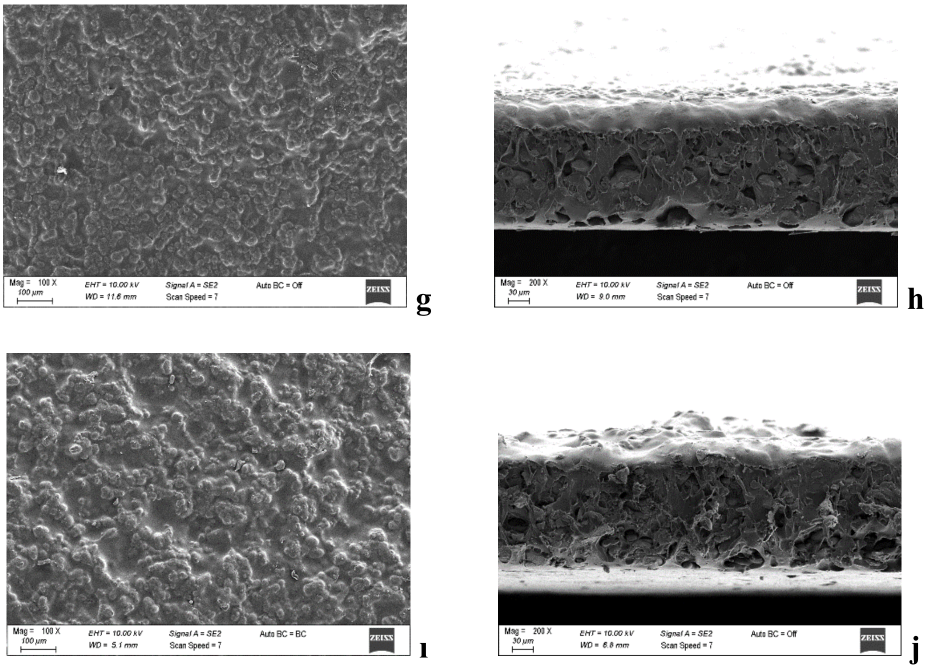


Figure 3. SEM images of banana peel incorporated PVA/gelatin biocomposite films. (a-b) PGB-1 (c-d) PGB-2 (e-f) PGB-3 (g-h) PGB-4 (ı-j) PGB-5

3.3 Visual aspect and color properties of biocomposite films

Visual characterization revealed that the surface of PVA/gelatin films was smooth without pores or cracks (Fig. 4). The developed flexible biocomposite films were easily peel off from the casting plates and showed good handling ability. The neat PVA/gelatin films were almost colorless and transparent. The banana peel powders were homogenously dispersed in the polymer film matrix. The color of neat PVA/gelatin films was changed due to the natural color of the incorporated banana peel powder. The color of PVA/gelatin films turned to a very slight yellowish color with the incorporation of banana peel. Especially, the 2% banana peel powder incorporated film (PGB-5) became less transparent.

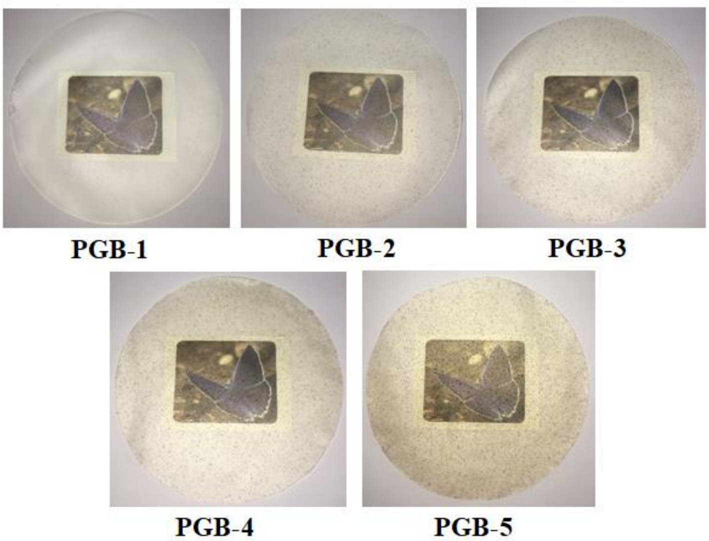


Figure 4. Visual aspect of banana peel incorporated PVA/gelatin biocomposite films.

Color parameters of PVA/gelatin films incorporated with different concentrations of banana peel are presented in Table 2. The concentration of incorporated banana peel powder had an influence on the color parameters of the resulting biocomposite films compared to the neat PVA/gelatin films. As listed in Table 2, PVA/gelatin/banana peel films indicated higher a* (redness/ greenness) and b* (yellowness/blueness) values, however, lower L (dark–light) and whiteness index values as compared with neat PVA/gelatin film. The L data showed that banana peel incorporation decreased the lightness of the neat film. The a* values of all the films varied from -0.77 to 0.73, with the highest value observed in the PGB-4 film. The improvement of a* values in biocomposite films demonstrated the tendency of films towards redness. The increased yellowness index and b* values was evidence of change of films' color towards yellowness. The yellowness of films increased from 13.53 to 24.87 with increasing banana peel content from 0.5 to 2.0, respectively. The variation in film color may be due to the natural pigments present in the banana peel [32]. Banana peels contain several bioactive compounds that influence the color of the resulting biocomposite films. The primary pigments are phenolic compounds (anthocyanins, epicatechin, catechin, gallic acid, tannins), flavonoids, and carotenoids, which impart yellow to brown hues [33]. Additionally, carotenoids (such as β-carotene and lutein) contribute to yellowish tones, while the presence of chlorophyll residues in unripe peels can introduce greenish shades. The combination and transformation of these natural pigments during film formation result in variations in the final color of the biocomposite films [34].

In certain applications, such as food packaging designed for light-sensitive products, reduced film transparency can be advantageous, as it minimizes light transmission and thereby protects the product from photo-oxidative degradation and quality deterioration [35]. Conversely, in applications where visual clarity and product visibility are critical—such as consumer packaging intended to showcase the contents—decreased transparency is considered undesirable, as it negatively affects the aesthetic and marketing appeal of the packaged product [36].

Table 2. Color parameters (L*, a*, b*), yellowness index, whiteness index and ΔE of banana peel incorporated PVA/gelatin biocomposite films.

Film	Peel Amount (%)	L*	a*	b*	ΔE	Yellowness Index	Whiteness Index
PGB-1	0	88.52	-0.77	6.80	-	10.97	86.63
PGB-2	0.5	87.00	-0.16	8.24	2.18	13.53	84.60
PGB-3	1.0	85.20	0.23	9.79	4.57	16.42	82.25
PGB-4	1.5	83.58	0.73	11.38	6.90	19.46	80.00
PGB-5	2.0	80.36	1.23	13.99	11.05	24.87	75.86

3.4 Surface wettability of biocomposite films

The biocomposite films' water contact angle (WCA) was determined to evaluate the surface wettability behavior (Fig. 5). Both PVA and gelatin are hydrophilic polymers. The neat PVA/gelatin film had the lowest WCA value. The WCA value of the neat PVA/gelatin film was 65.0 °, higher than the value (45°) reported by Yang et al. [37]. The contact angles for the biocomposite films PGB-2, PGB-3, PGB-4 and PGB-5 were 82.03°, 95.62°, 99.40° and 108.54°, respectively. Results indicated that the banana peel incorporated films were more hydrophobic as compared to the neat PVA/gelatin film. This can be explained by the reduced presence of hydrophilic free functional groups on the films' surface due to interactions between hydrophilic and carboxylic groups of banana peel components and those of PVA and gelatin [38]. This interaction could be attributed to the reorientation of the functional groups on the film surface and resulted in a less hydrophilic surface by forming a compact surface structure [38]. In addition, banana peel's inherent hydrophobic non-polar components (like lignin, lipids, and waxes) can migrate to the film surface, thereby decreasing the overall surface energy and enhance hydrophobicity [39]. High WCA values and hydrophobicity are important for many bio-related applications and particularly for food packaging purposes [28].

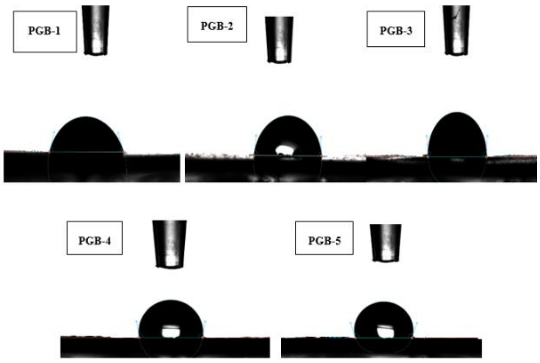


Figure 5. Water contact angle analysis images of banana peel incorporated PVA/gelatin biocomposite films.

3.5 Mechanical properties of biocomposite films

The thickness and mechanical properties including elongation at break (EAB%), tensile strength (TS), and Young's modulus (YM) of biocomposite films based on a PVA/gelatin as control and those reinforced with banana peel (0-2 %) are presented in Table 3. The control film, PGB-1 and PGB-2 had similar average thicknesses (0.24 mm). The addition of banana peel at higher ratios as 1.5 wt.% and 2.0 wt.% led to a slight increase in the average thickness of the films related to the increase in the total solid content. Similarly, an increment in thickness of PVA/gelatin film incorporated with bacterial cellulose nanowhiskers has been reported [9].

Tensile strength of the neat PVA/gelatin film was 7.15±0.5 MPa. This result was similar to the reported TS values (7.91 and 8.48 MPa) for PVA/gelatin films [37,40]. The TS of the banana peel incorporated biocomposite films ranged from 6.51±0.6 to 7.84±1.4 MPa (Table 3). The TS values increased in the neat film by incorporating banana peel up to 1.0 wt.%. The availability of hydroxyl groups of banana peel had the ability to interact with the film matrix and form hydrogen bonds [9]. This will result in a strong interfacial interaction between banana peel and the film matrix as well as an increase in TS due to good stress transfer [41]. However, this positive influence of the banana peel on TS was over in PGB-4 and PGB-5,which scored TS values lower than the neat film. The decrease of TS was instead related to the low aspect ratio and the lack of interaction and adhesion between the peel and the film matrix [41]. The addition of banana peel powder significantly improved the elongation at break performance of all biocomposite films. The EAB of the neat PVA/gelatin film increased from 63.49±4.1% to 87.94±8.5 % with the addition of 1.0 % banana peel powder. The further increase of peel powder content to 1.5 % and 2 % decreased the EAB to 80.81±19.9 and 66.5±2.5, respectively. The observed reduction in EAB values with the highest peel powder content can be attributed to the insufficient interfacial adhesion among the components, the potential aggregation of filler particles within the matrix, which may result in ineffective stress transfer between the peels and the polymer matrix [42]. This decrease in EAB indicates a reduction in film flexibility. While the film remains flexible, the observed reduction in elongation at break may moderately restrict its capacity to accommodate deformation or conform to irregularly shaped products, potentially affecting its performance in applications where high pliability is desired.

Young's modulus decreased from 66.90 ± 6.6 MPa (control) to 49.17 ± 11.3 MPa at 1.5 % peel content. At the 1.5% filler content (PGB-4), the composite exhibits a minimum in Young's modulus, indicating a critical transition point where excessive particle loading begins to compromise the polymer matrix. The observed sharp decline in tensile strength, coupled with a reduction in elongation at break, suggests that incipient particle agglomeration creates stress concentration sites and weak interfacial adhesion, thereby overriding the initial plasticizing effect and initiating mechanical failure. However, a slight increase to 59.79 ± 13.6 MPa at 2 % suggests that higher filler loading restricted polymer chain mobility and increased matrix rigidity. At elevated peel powder loadings (2%), the films exhibited increased stiffness, as evidenced by the higher Young's modulus, due to restricted polymer chain mobility; however, this also rendered the films less ductile and more brittle, leading to a concomitant reduction in elongation at break. A similiar trend was observed for the pomegranate peel incorporated starch based films [43].

Table 3. Thickness and mechanical properties of banana peel incorporated PVA/gelatin biocomposite films.

Film	Peel Amount (%)	Thickness (mm)	Tensile strength (MPa)	Elongation at break (%)	Young's modulus (MPa)
PGB-1	0	0.24±0.01	7.15±0.5	63.49±4.1	66.90±6.6
PGB-2	0.5	0.24±0.007	7.84±1.4	87.50±18.3	51.96±12.3
PGB-3	1.0	0.24±0.02	7.78±0.2	87.94±8.5	49.91±11.7
PGB-4	1.5	0.25±0.02	6.59±0.4	80.81±19.9	49.17±11.3
PGB-5	2.0	0.26±0.01	6.51±0.6	66.5±2.5	59.79±13.6

3.6 Thermal properties of biocomposite films

The thermogravimetric analysis of the films demonstrated that all biocomposite films exhibited fairly similar thermal behavior with four main of weight loss regions under nitrogen atmosphere (Fig.6). The biocomosite films were able to preserve more than 90% of their weight at 135°C. The initial weight loss in the region from 50 to 150°C was due to the evaporation of physically absorbed water linked with the hydrophilic groups of the polymer network structure. The significant weight loss of approximately 35% occurred in the second weight loss step between 150 and 280°C. The structural depolymerization, dehydration and decomposition of PVA/gelatin based biocomposite films happened at the second step. The third step was between 280 and 475°C, indicated the complete volatilization of the polymer products, followed by the carbonization of residual organic matter above 475°C.

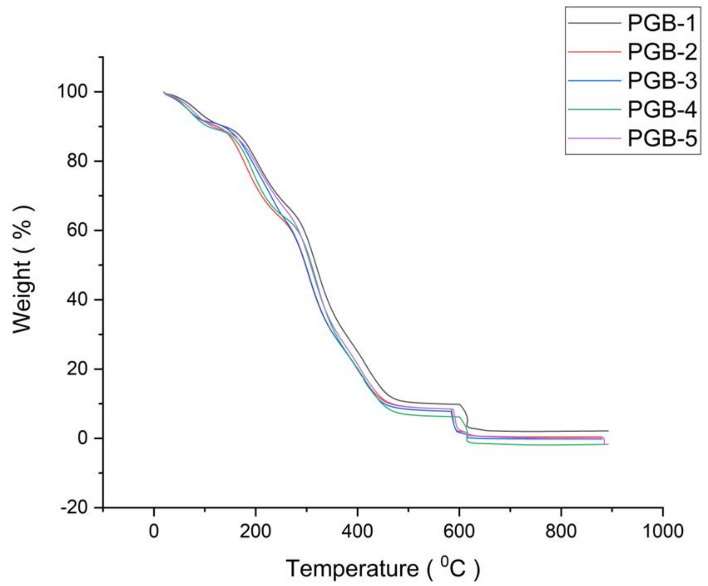


Figure 6. Thermal gravimetric analysis of banana peel incorporated PVA/gelatin biocomposite films.

4. Conclusions

Banana peel was used as a green filler in the PVA/gelatin matrix from 0.5 to 2 wt.% concentration for the development of biocomposites using the solution-casting method. The biocomposite films showed improved mechanical characteristics in terms of tensile strength up to 1 wt.% banana peel addition. Banana peel incorporation lowered the transparency of neat films. The water contact angles of films exhibited a significant difference after the incorporation of banana peel. The incorporation of banana peels enhanced the surface hydrophobic property of the biocomposite films. Banana peels hold promise as a sustainable alternative to conventional materials, contributing to environmental conservation efforts. Therefore, banana peel as a biofiller presents a viable alternative to inorganic fillers, especially for the design of biodegradable, eco-friendly packaging solutions, such as on-the-go food wrapping materials. Future studies could focus on evaluating the long-term barrier, thermal, and biodegradation performance of the films, as well as their suitability for specific food packaging applications, to further expand their applicability in sustainable packaging solutions.

Ethics in Publishing

There are no ethical issues regarding the publication of this study.

Author Contributions

Büşra Balı and Elifnur Baş: Conceptualization, Investigation, Formal analysis, Data collection. Neşe İşman: Formal analysis, Writing-review and editing. Pınar Terzioğlu: Supervising, Conceptualization, Formal analysis, Writing - original draft preparation, Writing-review and editing, Funding acquisition.

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