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Bee products loaded polymeric films as a potential dressing material for skin treatments

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Highlights:

- Successful incorporation of honey, pollen and propolis into polymeric films.
- Evaluation of physicochemical properties for wound dressing potential.
- Bioactive substance addition improves existing properties.
- Observation of high antioxidant and antibacterial activity.

Abstract: In this study, bee products such as honey, pollen, and propolis were directly incorporated into the polymer structure prepared based on chitosan and gelatin to obtain biofunctional thin films. Thin films were evaluated according to their potential as wound dressing material with different physicochemical analyses such as chemical structure, morphology, water retention capacity, wettability, degradability and water vapour permeability. The results obtained varied according to the type of bioactive substance. The contact angle and water vapour permeability properties of chitosan: gelatin films selected as control films were improved by adding bioactive substances. In addition, when evaluated in terms of biological properties, it was observed that the bee products loaded thin films exhibited high antioxidant and antibacterial activity. The preliminary optimization results obtained from this study may have the potential to be an initial idea for future studies to be carried out in the material-bee product composition, especially in material production processes.

Keywords: chitosan; gelatin; pollen; propolis; honey; thin film; wound dressing

1. Introduction

As the largest organ in the body, the skin protects aganst external factors such as ultraviolet radiation, toxic chemicals, and microbes [1]. Every day, millions of living beings develop skin wounds due to various accidents or diseases. These wounds are divided into two types depending on the healing time and etiology: acute and chronic wounds [2,3]. Acute wounds generally characterized by low bacterial load, usually heal within the predictable and expected time frame of normal wound healing [4]. However, chronic wounds are a major concern for clinicians due to the delayed wound-healing process that can last several months or years. One of the numerous and challenging biological processes involved in wound healing is restoring damaged tissue with healthy tissue. The phases of inflammation, proliferation, and remodelling comprise the wound healing process. It can be challenging to treat wound infections systemically for a variety of reasons, including limited medicine delivery to the infection site. To speed up the healing process, local administration of drugs such as antimicrobial creams, lotions, and therapeutic gels are applicable therapeutic options in the treatment of wound infections. However, these therapeutic agents may not be effective due to the presence of structures such as biofilm and the deep involvement of skin layers [5].

To get around these restrictions, one of the most often utilized treatments for wound healing is the use of wound dressings. Films, hydrogels, hydrocolloids, foams, and fibers are examples of wound dressing materials [6]. The films can be used to treat wounds and provide the wound site with antibacterial and anti-inflammatory ingredients. Films have the qualities of being both biocompatible and biodegradable. They are simple to use in challenging environments due to their mechanical qualities and flexibility [7]. In addition to these, films provide an evaluation of the wound bed without removing the dressing, let some moisture escape, and act as an efficient barrier against external contamination [8]. It also facilitates controlled and sustained drug release by leaving a thin and transparent film between the excipients and the drug on contact with the skin. Film formulations can be developed in a variety of forms, including solutions, gels, or emulsions.

Functional wound dressings obtained by loading thin films with drugs can serve as a temporary support material for tissue integrity and can also carry bioactive components that accelerate the wound healing process. The term drug here can include plant extracts, drug molecules, growth factors, vitamins, nanoparticles, and natural bioactive agents. Among the natural bioactive agents, bee products such as honey, bee pollen, propolis, and royal jelly have been used in both tissue engineering and wound healing applications [9]. The utilization of honey and other bee products dates back to ancient times. Honey has been used for therapeutic purposes around the world for thousands of years. Historical records that have survived to the present day show that ancient Egyptians, Greeks, and Romans treated wounds with honey [10]. Propolis as a resinous mixture collected by honeybees from plant sources contains different compounds such as resin, wax, essential oil, phenolic acids, cinnamic acid, caffeic acid, terpenes, flavonoids, esters, amino acids, sugar, sterols, steroid hydrocarbons, and minerals [11,12]. As a result of this rich composition, it has been known that propolis has antimicrobial [13], antioxidant [14], and anti-inflammatory properties [15]. It also supports wound healing by stimulating epithelial regeneration [16] and regulating the deposition of extracellular matrix [17]. As another valuable bee product, bee pollen is characterized by high antimicrobial activity as well as bactericidal action [18].

To date, a substantial body of research has been conducted to investigate the impact of bee products on wound healing processes. As materials scientists, our objective in this study is to illustrate and analyze

the alterations that occur in the final material as a consequence of the potential interactions between bee products and polymeric materials. For this purpose, honey, pollen, and propolis were selected as bee products that have been proven to have biological activity and are frequently used. Chitosan and gelatin, which are biodegradable and biocompatible natural polymers frequently preferred in the literature, were used as control samples. The polymer was processed into thin films by solvent casting method which is a cheap, uncomplicated, and fast production process. Composite films were produced by adding equal amounts of honey products to the structure and compared with the control sample and the changes in the structure and the potential interaction between polymers and honey products were discussed with different characterization methods. It is thought that the study will provide important contributions, especially for researchers working in material design as wound dressing material.

2. Methods

2.1. Materials

Chitosan with medium molecular weight, gelatin, and glycerin were purchased from Sigma Aldrich, USA. Bee products such as pine honey, propolis, and pollen were supplied from a beekeeping producer in the Arslanköy district of Mersin, Türkiye.

2.2. Preparation of solutions and casting process

Chitosan: gelatin film (control sample) and composite films with equal amounts of different bee products were prepared using a conventional solvent casting. First, each polymer solutions were prepared separately. The calculated amount of polymer (2%, wt) was weighed and dissolved in an acetic acid solution (1%, vol) for the chitosan solution. The gelatin solution was prepared by dissolving the calculated amount of polymer (4%, wt) in distilled water at 65 ℃ by mixing it with a magnetic stirrer until it became completely homogeneous. Afterward, 2 mL of gelatin solution, 0.5 mL of chitosan solution, and a certain amount of glycerin (20 µL) were mixed. The mixture was stirred at room temperature for 30 min on a magnetic stirrer to ensure homogenization. Then, the solution was poured into Teflon molds with a diameter of 4 cm and carefully spread to obtain a film. The polymeric film was solidified by evaporating the solvent at 30 ℃ overnight using a temperature-controlled oven. After 24 h of incubation, the films were peeled off from the molds and stored in polyethylene bags.

To produce the bee products loaded films, composite solutions were obtained by adding equal amounts of bee products to the polymer solution detailed above. The obtained solutions were used directly for the preparation of the polymer films in the above order. All samples produced in the study, together with their contents and abbreviated names are shown in Table 1.

Table 1. The composition and abbreviated names of investigated films.

Sample name	Polymer amount, g	Additive	Additive amount, g
Control (CG)	0.09	-	-
CG@HON	0.09	Honey	0.06
CG@POL	0.09	Pollen	0.06
CG@PRO	0.09	Propolis	0.06 g (in 1 mL ethanol)

2.3. Morphology

The morphological observation of thin films was carried out by optical and scanning electron microscope images. The images were obtained at 40x magnification for an optical microscope with a digital camera mounted on the microscope. For SEM analysis, samples were first coated with a thin layer of platinum using a sputter coater and then images were taken at 500x magnification at 5 kV accelerating voltage using SEM (FE-SEM Zeiss/Supra55, Quanta 400F Field Emission, USA).

2.4. Chemical structure

The chemical structures of the obtained thin films were determined using Fourier Transform Infrared (FTIR) spectrum obtained by using a spectrometer (Perkin-Elmer Spectrum 1000, USA), equipped with an attenuated total reflection (ATR) accessory. The spectra of films were recorded from 4000 to 400 cm^{-1} at a resolution of 4 cm^{-1} with 128 scans.

2.5. Swelling ratio

The swelling behaviour of the thin films was determined by measuring the time-dependent weight change of the samples incubated in PBS (pH 7.4). For this purpose, film samples cut into 1x1 cm^2 were first weighed (W_o). The samples whose initial weights were recorded were placed in centrifuge tubes filled with 10 mL PBS solution. At the specified time intervals (10, 20, 30, 60, 90, and 120 min), the excess water on the surface of the samples taken from the PBS was absorbed onto a filter paper, and the weight was recorded (W_t). The following equation calculated the swelling ratio (wt %) based on gravimetric measurement. Tests were carried out three times.

$$\text{Swelling ratio, \%} = [(W_t - W_o)/W_o] \times 100 \quad (1)$$

2.6. Contact angle

The contact angle of the films was determined by measuring the water contact angles obtained according to the sessile drop method, which is a common method for determining the macroscopic surface property on the wettability of solid surfaces, with a contact angle measurement system (). For this, the film sample was fixed on the glass surface and a drop of water was dropped. The equilibration time of the drop was determined as 5 seconds. The average contact angle value was calculated from the measurements taken at different locations of the films.

2.7. Water vapour transmission ratio

The water vapour transmission ratio (WVTR) of the thin films was determined according to the method established by Sripatrawan *et al.* [19]. Briefly, films were sealed in centrifuge tubes (R = 15 mm) containing deionized water (10 mL) and weighed (W_1). Then, the tubes coated with the film were placed in an incubator set at 37 ℃ and 75% RH using saturated NaCl. The tubes were weighed at 24-hour time intervals (W_2). Tests were done three times and WVTR values were determined as the following equation:

$$WVTR = (W_1 - W_2) / (Axt) \quad (2)$$

where A represents the surface area of tubes and t represents definite times.

2.8. Degradability

The degradability (weight loss) of the thin films was determined by measuring the time dependent weight change of the samples incubated in PBS (pH 7.4) at different temperatures (25 ℃ and 37 ℃). The film samples were weighed and their weights were recorded. Then, the samples were immersed in 15 mL tubes containing PBS buffer (pH 7.4) and incubated at 37 ℃ and 25 ℃. At certain times thin film samples were taken, dried and their weights were measured. The weight loss of the samples was determined according to equation below:

$$\text{Weight loss, \%} = [(Wi - Wf)/Wi] \times 100 \quad (3)$$

Wi and Wf represent initial and final weights of the thin film samples.

2.9. Antioxidant activity

The antioxidant activities of films were investigated using slight modifications to the method described by Braga *et al.* [20]. Briefly, 1 mL of freshly prepared 0.5 mM methanolic DPPH solution was added to the solutions containing 3 mL of film samples (0.08 g) and the samples were incubated in the dark for 4 hours. Then, the absorbance of the samples was measured at 517 nm using a UV-Vis spectrophotometer. The DPPH radical scavenging activity (%) was calculated using the following equation.

$$\text{Radical scanning activity, \%} = [(Abs_{control} - Abs_{sample})/Abs_{control}] \times 100 \quad (4)$$

where $Abs_{control}$ is the absorbance of the methanolic solution of DPPH without samples and Abs_{sample} is the absorbance value for the sample extracts.

2.10. Antibacterial activity

Two bacterial strains, gram (+) *Staphyloccocus aureus* (ATCC 29213) and gram (-) *Escherichia coli* (ATCC 25922), were employed to study the antibacterial activity of thin films. Nutrient broth (NB, Merck, Darmstadt, Germany) was used for the preparation of bacterial cultures suspension and evaluation of the colony forming unit (CFU). Before analysis, the films were initially sterilized under UV light in laminar flow hood. With a few minor adjustments, the Plate Count technique was used with bacterial strains. After being weighed, 20 mg of sample was put into sterile centrifuge tubes. The tubes were filled with 50 µL of bacterial suspension and 3 mL of growth media. After that, the tubes were incubated at 37 ℃ for 24 hours in a shaker. Following incubation, the solutions were diluted to 10^{-5}. Three parallel plates containing plate count agar were infected with 100 µL of the diluted bacterial solutions, which were then equally spread out using sterile cotton swab sticks. Colonies were enumerated to determine the antibacterial action following a 24-hour incubation period at 37 ℃.

3. Results

Pollen, propolis, and honey, as natural components, have attracted great attention in biotechnological and medical applications in recent years [21,22]. These substances have rich biological properties and when

functionalized with polymer thin films, they can be effectively used for the treatment of skin defects such as wound healing and infection treatment thanks to their strong antioxidant, antimicrobial, and anti-inflammatory properties. Among them, especially propolis can help prevent bacterial and viral infections. Pollen and honey accelerate healing processes as natural antibacterial agents. The integration of these substances with polymer thin films provides controlled release of bioactive agents, making treatment processes more effective and long-lasting. In addition, the biocompatibility of these natural components ensures their safe use, facilitating the integration of natural treatment methods with modern medicine.

In this study, functional composite thin films as potential dressing materials for skin treatments were synthesized by adding honey, pollen, and propolis to polymer solution. Following the experimental steps illustrated in Figure 1, the produced thin films were characterized to determine their physicochemical, antioxidant and antibacterial properties. As a preliminary optimization study, this work aims to determine how these biocomponents, whose therapeutic properties have been proven both traditionally and scientifically for many years, are distributed in the polymer structure, the possible mechanisms, and the extent to which they affect the characteristic and basic microbiological properties of existing polymer thin films. For this reason, the solvent casting method was preferred as an easy, reproducible, inexpensive, and short production process. The optimum ratios obtained from the previous studies of the research group were used as the polymer solution composition [23,24]. Thin films were successfully produced by adding equal amounts of bee products to the polymer structure.

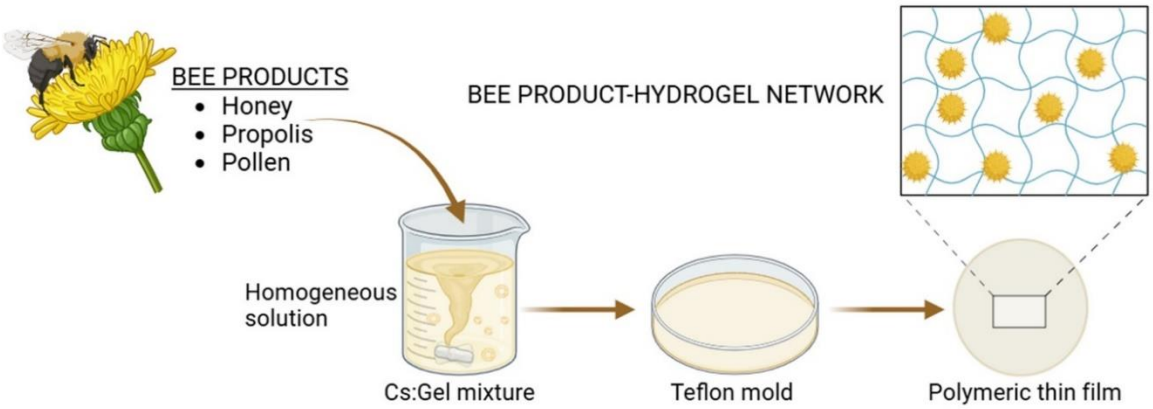

Figure 1. The concept of the study illustrates the experimental steps of polymeric thin film production by loading with different bee products including honey, pollen, and propolis.

3.1. Physicochemical characterization of thin films

Thin films provide antiseptic, antimicrobial, and healing effects when functionalized with bioactive agents. However, these contributions must preserve the existing characteristics of the films. One of these features is the preservation of the existing transparent structures of polymer thin films after the addition of the bioactive component. Transparency increases the visibility of the wound area and facilitates the monitoring of the treatment process [25]. In addition, transparent films provide a cosmetic advantage during the treatment process by increasing the patient's comfort, because they do not attract attention aesthetically and are not noticeable from the outside. Figure 2 shows photographs of the thin films obtained in this study. It is evident that transparent structural integrity is maintained in all samples. On the other hand, the colour change observed in the films is due to the characteristic natural colour of bee

products. This physical observation can give a preliminary idea about the homogeneous distribution of biocomponents in the polymer structure.

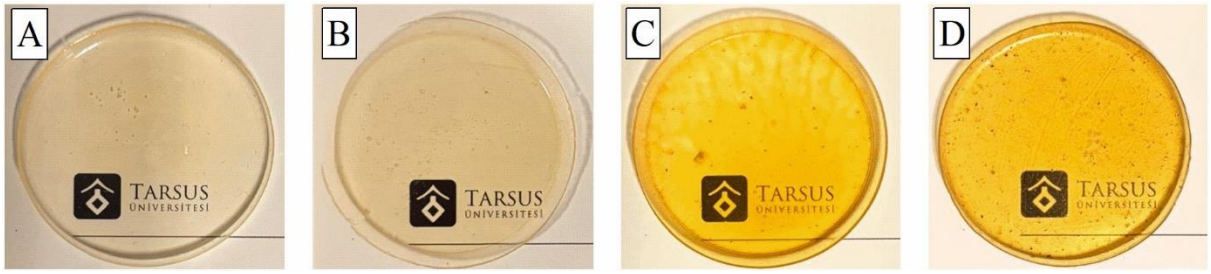

Figure 2. Daylight photographs of thin films produced by solvent casting. The text on the ground is used to show that all films are transparent. A: CG control film, B: CG@HON, C: CG@POL, and D: CG@PRO bee products added thin films.

To examine the distribution of the polymers within each other and the bee products included in the structure within the polymer structure, the optical microscope and SEM images presented in Figure 3 were used. Here, we can say that in the control sample (Figure 3A), chitosan and gelatin show a homogeneous distribution within themselves. Although there is a homogeneous distribution, when the SEM image in Figure 3B is examined, there are some cracks and surface roughness on the surface of the control sample. It is seen that this morphology is improved by adding bee products to the polymeric structure. With the addition of bee products, smoother structures without fractures or cracks on the surface were obtained. In addition, the elliptical particles dispersed in the morphological structure in Figure 3E belong to pollen grains. These also appear as bubbles trapped inside the polymer structure in the SEM image (Figure 3F). These are similar to images from another study reporting different pollen types [26].

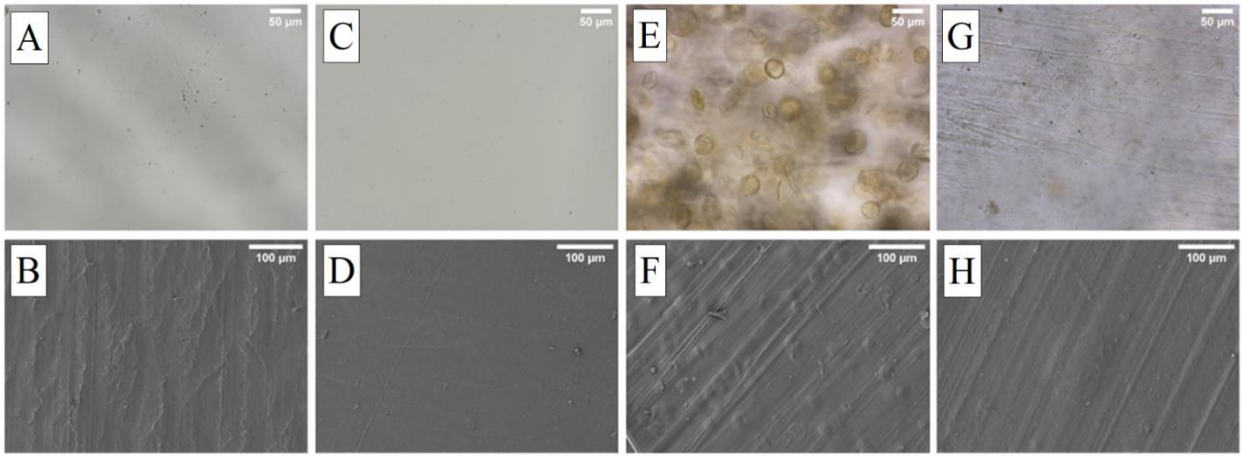

Figure 3. The pictures obtained using an optical microscope (at 40X magnification) and SEM (at 500X magnification). **A, B:** CG control film, **C, D:** CG@HON, **E, F:** CG@POL, and **G, H:** CG@PRO bee products added thin films.

Studying the bond structure of the components in the film is important to determine the physical or chemical interaction of the bioactive component with the polymer structure. This interaction was evaluated by comparing the FTIR spectra shown in Figure 4. Firstly, when the spectrum of the control sample CG film was evaluated, it was seen that a similar spectrum was obtained with previously prepared solvent-cast

films based on chitosan and gelatin [27–29]. The basic mechanism of the interaction between these two polymers is based on the absorption of the C = O groups of gelatin by the functional N-H groups of chitosan, resulting in the formation of strong hydrogel bonds, as also reported by Vo *et al.* [29]. The broad band at approximately 3290 cm^{-1} is attributed to O-H stretching and N-H stretching vibrations. The 1637 cm^{-1} and 1548 cm-1 peaks are associated with amide I (C = O stretching) and amide II (N-H bending and C-N stretching vibrations) bands, respectively. A group of signals in the 1000-900 cm^{-1} range is attributed to the characteristic saccharide bands of chitosan [28]. The peaks in the spectrum of the control sample were also observed in composite films produced with honey, pollen, and propolis added to the structure as bioactive compounds. In composite films produced with honey, pollen, and propolis added to the structure as bioactive components, peaks in the spectrum of the control sample continued to be observed. Only a decrease in the intensities of the peaks occurred and slight shifts were observed compared to the control CG sample.

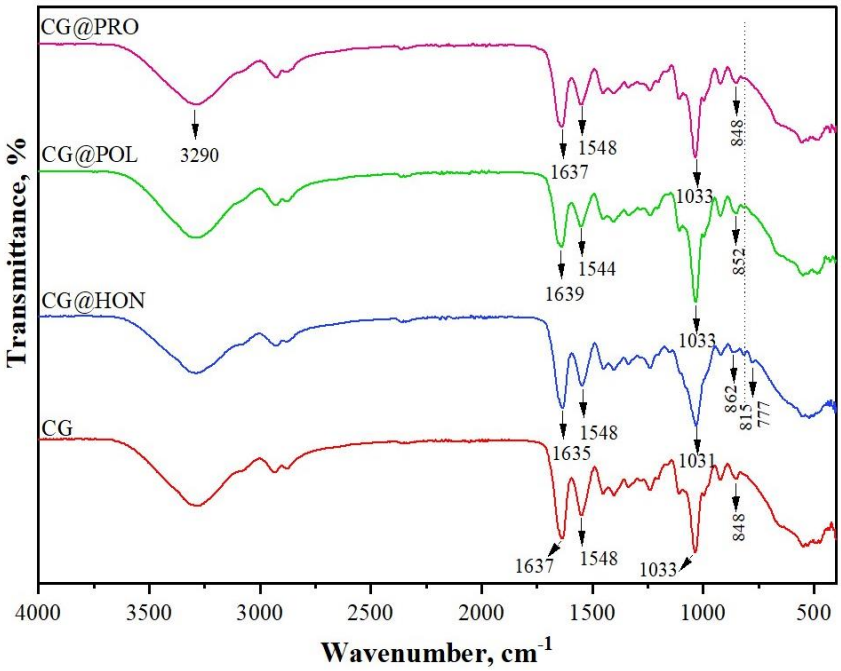

Figure 4. FTIR spectrum of control (CG) and bee products loaded composite films (CG@HON, CG@POL, and CG@PRO).

Contact angle measurement provides information about the wettability of the surfaces of films. The wettability plays an important role in determining the function of the wound dressing [30]. Surface hydrophobicity/hydrophilicity is effective in directing cellular processes such as cell initiation, adhesion, and migration during wound healing. High water contact angle values (>90 °) indicate higher hydrophobicity of the surfaces. Figure 5A presents photographs of water droplets on film surfaces captured at 5 seconds. The average contact angle values obtained from these photographs are given in the graph given in Figure 5B. The contact angle values of films were measured as 100.78±0.14 for the control sample (CG), while they were measured as 88.03±0.02, 88.68±0.05, and 88.44±0.02 for CG@HON, CG@POL and CG@PRO films, respectively. The addition of bioactive components to the polymer structure caused a change in the contact angle of the surface. Especially with the addition of pollen and honey, there was a significant change compared to the control sample (** $p<0.05$). With the

maintained hydrophilicity, protein adsorption and bacterial adhesion may be reduced and cell compatibility may be increased [31]. Only in the CG sample, a transition to hydrophobic properties was indicated with the contact angle value. In this case, the ratio and concentration of the polymer composition may need to be optimized in terms of surface hydrophilicity.

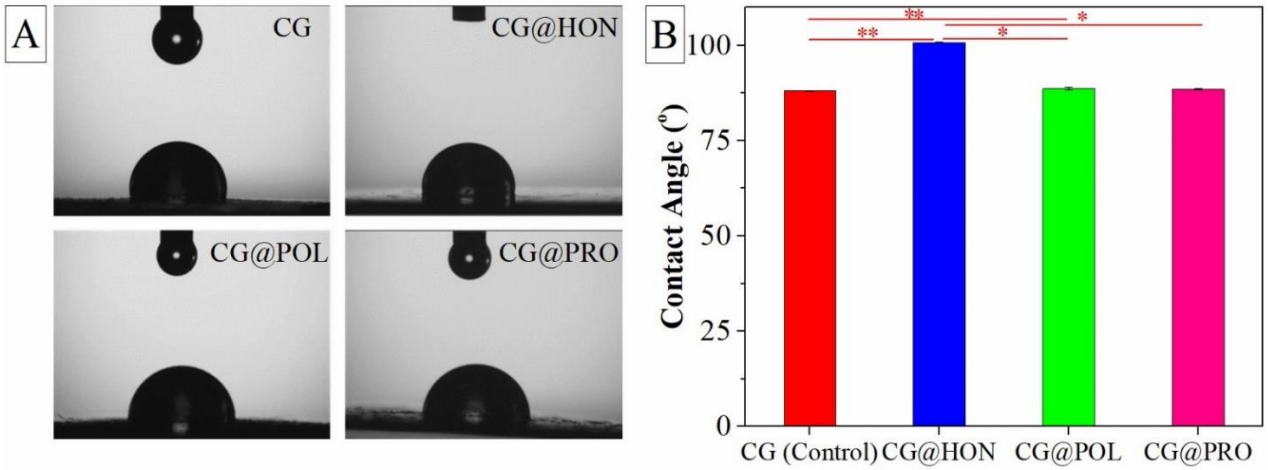

Figure 5. Contact angle analysis of thin films. A: photographic images of the water droplets on the surface of thin films and B: measured contact angles of the corresponding samples. Data are presented as mean ± SD. *, ** $p < 0.05$

Parallel to wettability, the swelling behavior of thin films is a parameter that can provide preliminary information about whether the materials have the potential to be used as wound dressings. The swelling ratio is important for determining the performance of wound exudates. In Figure 6A, the time-dependent swelling ratios of the films in PBS (pH 7.4) were presented. It is observed that all samples swell rapidly by absorbing water within the first 10 minutes due to their hydrogel structure and have a swelling ratio of approximately 110-210% within 60 min. In the following period, it is observed that the swelling ratio values of the CG@HON and CG@POL samples could not be calculated after 60 and 120 minutes, respectively. These samples tended to disintegrate as a result of their possible low mechanical properties and therefore weight measurement could not be made. In other words, although honey and pollen have the potential for wound healing applications, the addition of these bioactive components to the structure caused an unstable structure in the films in the aqueous state, which limited their use and applications. The control sample (CG) and the propolis-added thin films (CG@PRO) show a more appropriate swelling behaviour that supports the required function of the wound dressing by facilitating the absorption of wound exudate for a longer period and keeping the environment moist.

An ideal wound dressing is desired to have water barrier properties that can prevent microbial infections and water loss from the wound while controlling water vapor permeability [32,33] Therefore, another property evaluated in thin films is the determination of water vapor transmission rate (WVTR). The calculated percentage of WVTR values depending on time are given in Figure 6B. In accordance with the results of the Tukey test, no statistically significant difference ($p<0.05$) was identified between the control film and the films that had been loaded with bee products at either time interval. However, as demonstrated in Figure 6B, the WVTR values of all films that loaded bee products were lower compared to the control film. It means that adding honey, pollen, or propolis resulted in lower WVTR content of the chitosan and gelatin-based films. It might be due to the barrier properties of bioactive

compounds which are uniformly distributed within the hydrogel matrix and avoid the penetration of water vapor as also reported for chitosan/gelatin/nanocrystalline cellulose/calcium peroxide films studied by Khrazian *et al* [33]. Previous studies have reported that the WVTR value can vary between approximately 204 g/m^2 per day, 279 g/m^2 per day for a first-degree burn to 5138 g/m^2 per day for granulating wounds [34]. Accordingly, the bee products loaded films prepared in this study were found to decrease the WVTR of control films and exhibit WVTR values in the range of 484.90 ±43.28 to 439.01 ±20.52 g/m^2/h. Compared to the control sample, it can be suggested that it can provide an appropriate range for maintaining appropriate fluid balance on the wound surface. High WVTR values can lead to dehydration of the wound, so it is an important finding to see that the WVTR value decreases with the addition of bee products [35]. Here, the WVTR value can be optimized by increasing the amount of bioactive components.

In the evaluation made in terms of mechanical properties with preliminary observations, it can be said that the CG@PRO sample has a more flexible structure (Figure 6C). In addition, the fact that it can easily adhere to the skin when left directly on the skin is an advantage in terms of easy application (Figure 6D).

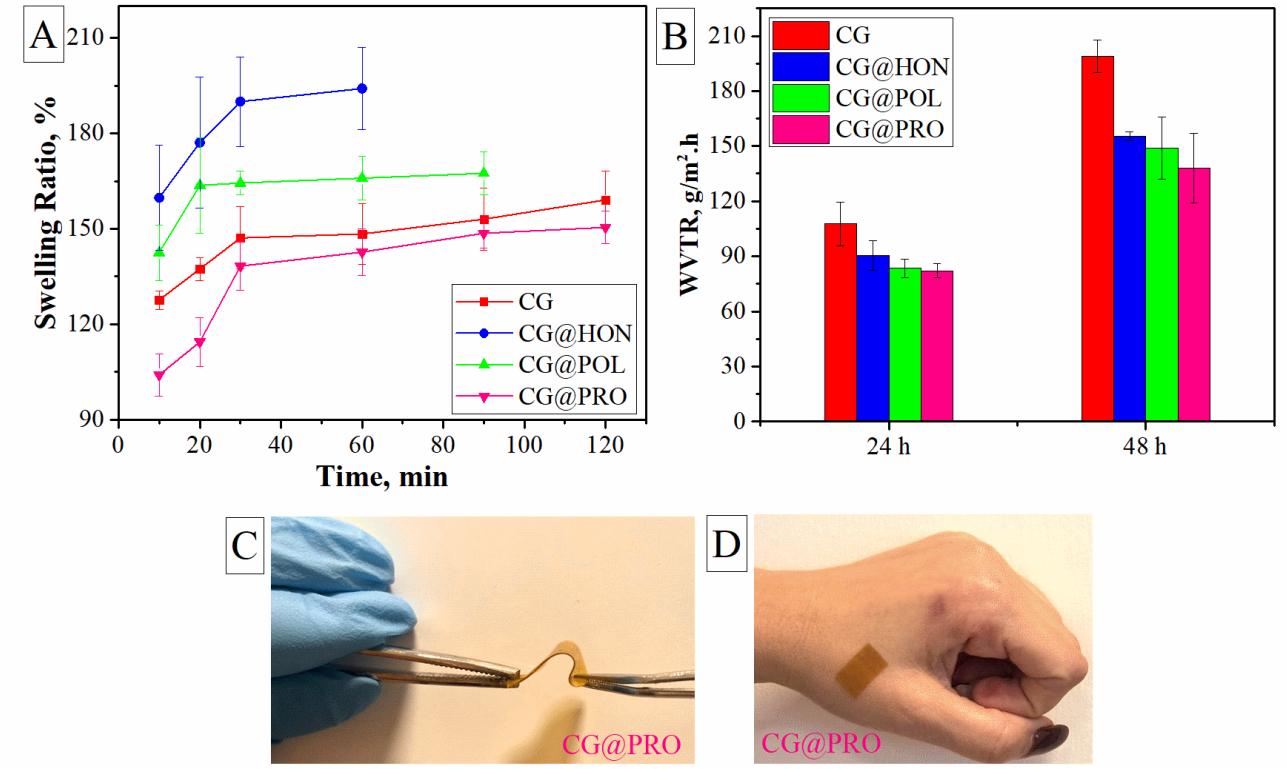

Figure 6. A: Swelling ratio, **B:** Water vapor transmission rate, **C:** Elastic structure of CG@PRO film sample, and **D:** Adhesive structure of CG@PRO film.

The biodegradability, a sought-after property in biomaterials, was investigated based on the change in weight of samples after incubation in PBS at two different temperatures. In this context, weight loss percentage values are presented in figures 7A and 7B for 1, 3, 5 and 7 days. It can be said that the change in temperature did not cause a significant change in the degradation results of the materials and that all samples decreased in weight over time, *i.e.* they were biodegradable. However, differences are observed in the weight loss (%) rates depending on their contents. The CG@PRO sample, which has one of the highest swelling rates, showed 100% degradation within the first 24 hours. Here, the material was completely dissolved in PBS. In addition, the CG@POL and CG@HON samples exhibited a similar

profile. In general, based on the degradability results, it can be said that the CG@PRO sample may be more suitable for short-term applications compared to other thin films.

In terms of biological activity, the antioxidant properties of the prepared thin films were determined by the DPPH radical test, and the results are shown in figures 7C and 7D. When the components with antioxidant properties interact with the DPPH radical, the absorption peak decreases. Compounds with antioxidant properties convert the purple DPPH structure into the yellow DPPH-H structure. Figure 7C shows that films loaded with bee products exhibited a significantly higher DPPH radical scavenging activity compared to the CG (control) films. The antioxidant activity of the films loaded with bee products increased more than 2.5-fold compared to the control group. CG@PRO, CG@POL, CH@HON, and CG thin films showed 95.02%, 90.81%, 62.73%, and 29.99% DPPH radical scavenging activity, respectively. The antioxidant activity of bare film was probably due to the presence of bioactive functional groups such as hydroxyl and amino groups of chitosan and gelatin [36]. Especially, in the study by Valizadeh *et al.*, they reported that the protonation of free -NH_2 groups along the chitosan backbone to -NH_3^+ plays an important role in the antioxidant properties of chitosan [37]. Free hydroxyl and amino groups in the structure of polymers react with free radicals and form stable structures [19]. The antioxidant activity of thin films prepared with bee products can be due to the phenolic compounds released into the medium. Phenolic compounds released from pollen and propolis-loaded thin films act as H donors and react with DPPH, converting the DPPH structure into the stable DPPH-H form.

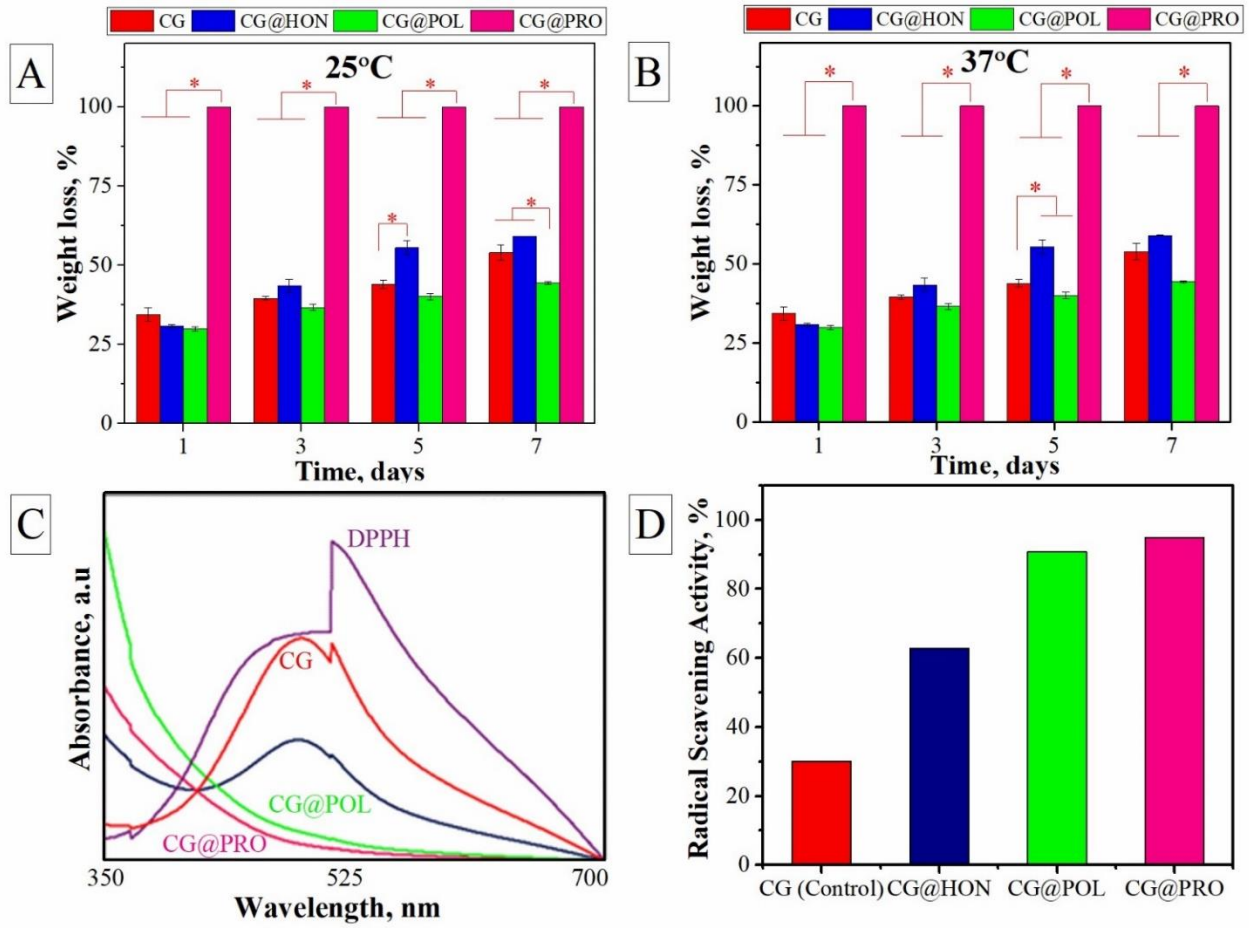

Figure 7. A: Weight loss (%) of films at 25˚C, **B:** Weight loss (%) of films at 37˚C, **C:** UV- Vis absorption spectra of DPPH solution and **D:** DPPH radical scavenging activity of thin films before and after mixed with bee products.

Previous studies have shown that bee products exhibit a broad-spectrum of antibacterial activity [38–40]. In this study, in order to show whether bee products exhibit antibacterial activity after being combined with polymers, their activities against gram-negative and gram-positive bacteria were studied using the plate counting method. The photographs and colony counting results are presented in Figure 8 and Table 2, respectively. The results indicate that the incorporation of bee products into polymeric film effectively enhances the antibacterial property. The antibacterial properties of the CG@PRO sample demonstrated slightly superior performance in comparison to the CG@POL and CG@HON samples.

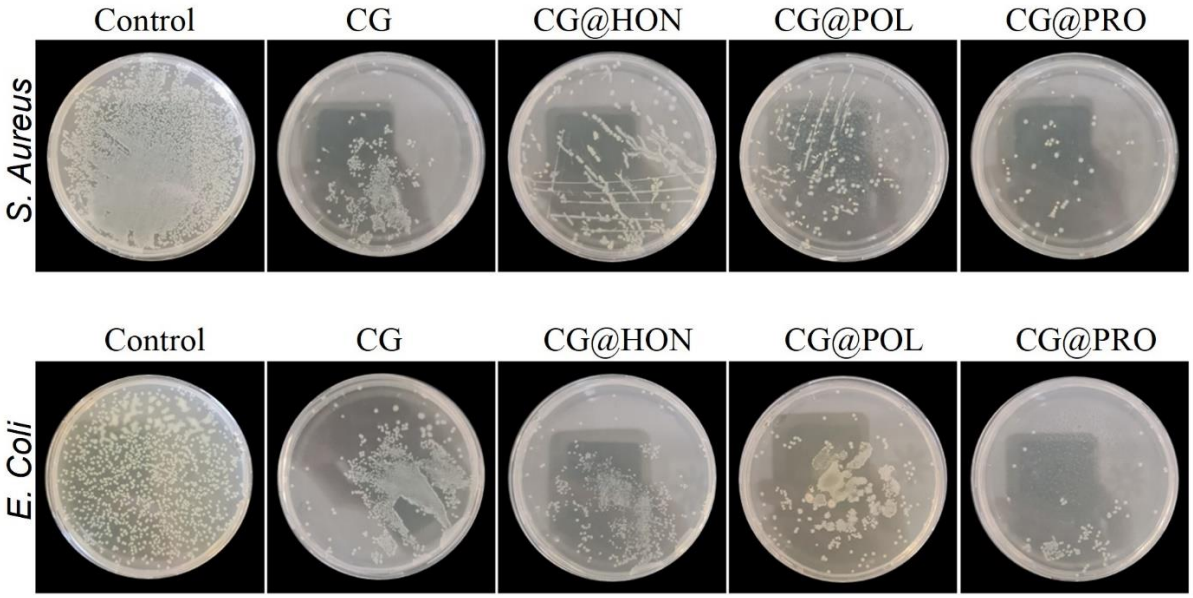

Figure 8. Plate counting method photographs of the control (without film), CG film, and bee products loaded films.

Table 2. Colony count data of the control (without film), CG film, and bee products loaded films obtained from the test results.

Sample name	Number of colonies (mean ± SD)	
	S. Aureus	***E. Coli***
Control (without film)	350>	350>
CG	265.66 ± 5.91	285.67 ± 4.78
CG@HON	223.67 ± 9.03	253.67 ± 6.34
CG@POL	129.33 ± 9.10	172.00 ± 5.71
CG@PRO	64.33 ± 6.24	95.00 ± 5.35

4. Conclusion and future perspective

Bee products have been an important raw material used by humanity throughout history. As seen in this study, bee products were used successfully as raw materials in the production of polymeric films, which are value-added biomedical materials. The bee products included in the polymer structure exhibited different characteristic features. The low mechanical integrity of the honey-added film (CG@HON) in an aqueous environment due to its high water retention property and fast release of honey has shown that it can be used for short-term skin renewal processes such as moisturizing. On the other hand, the high

bioactivity of pollen and propolis-added films reveals the potential of these films to be used as biocompatible antibacterial wound dressing films. In addition to their bioactive properties, the high-quality structural and biological properties (contact angle, elasticity, swelling ratio, antioxidant properties, antibacterial activity, *etc.*) of the films have shown the potential of these materials as biomedical products. In future studies, biocompatibility studies of these polymeric films produced with bee products in terms of wound healing properties may give a better idea about the potential use of these films. In addition, controlled release properties may be determined to develop effective wound-healing dressings. On the other hand, since bee products and chitosan can be used in food packaging, antibacterial active packaging studies can be conducted by using polymeric films produced by bee materials. Thanks to their elastic structure and suitable properties, these films might be investigated for their potential use in foods that are highly susceptible to microbiological spoilage such as cheese and meat products.

Acknowledgments

Authors' contribution

D.D., Conceptualization, methodology, supervision, writing- original draft preparation, writing—review and editing; O.K., formal analysis, methodology, investigation, writing- original draft preparation; S.L.İ, formal analysis, methodology, investigation, writing- original draft preparation; S.C., investigation, writing—original draft preparation. All authors have read and agreed to the published version of the manuscript.

Conflicts of interests

The authors declare that they have no conflicts of interest.

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