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Synthesis and characterization of polyvinyl alcohol-based bioplastic film incorporated with keratin extracted from duck feathers

Md. Lawshan Habib [a], Md. Hanif Munshi [a,b], Md. Kamruzzaman [a,*], Tama Baul [a], M. Mehedi Hasan [a,c]

[a] Department of Applied Chemistry and Chemical Engineering, Faculty of Engineering, Gopalganj Science and Technology University, Gopalganj 8100, Bangladesh
[b] Department of Textile Engineering, Uttara University, Dhaka, 1230, Bangladesh
[c] Department of Chemistry, Virginia Polytechnic Institute and State University, Blacksburg, VA, 24061, United States

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ABSTRACT

The growing environmental impact of petroleum-based plastics has led to increased interest in biodegradable alternatives. However, many bioplastics still face limitations in terms of cost, mechanical properties, and degradability. To address these challenges, this study aims to develop an eco-friendly bioplastic film. Our methodology involves utilizing discarded feather keratin sourced from duck feathers, which is then incorporated into polyvinyl alcohol (PVA). The PVA matrix, along with the keratin filler, provides the bioplastic film with the necessary attributes for biodegradability as well as imparting mechanical and thermal properties that make it suitable for a wide range of sustainable applications. The keratin was successfully extracted from waste duck feathers, resulting in a commendable yield of 79 %. The bioplastic film was prepared using different concentrations of the constituents and subsequently analyzed using various characterization techniques. The thermal and mechanical properties of the bioplastic exhibited a notable enhancement when compared to pure PVA. The prepared film's optimal composition was determined to be P5K0.05 (PVA 5 wt% and Keratin 0.05 wt%). The other characterization techniques, such as FTIR, SEM, and TGA, also exhibit a commendable agreement with the obtained results. The results of the cytotoxicity assessment indicated that the prepared bioplastic exhibits biocompatibility.

1. Introduction

The imperative of environmental sustainability has driven both the scientific and industrial sectors to explore biomass as a renewable source for developing environmentally friendly specialty materials. Raw materials derived from animal and plant sources, such as proteins, sugars, cellulose, and oils, exhibit immense potential as sustainable and cost-effective feedstock for a diverse range of applications with a focus on sustainability [1]. Simultaneously, the utilization of edible starch or protein for the formulation of packaging materials may engender a potential rivalry for precious food resources. Nonfood-borne keratin exhibits immense potential as a highly favorable contender for the development of biodegradable packaging materials [2]. Feathers, which possess a substantial keratin content of approximately 90 %, can be readily procured in significant volumes within the poultry sector. The annual production of feathers, a valuable byproduct, is estimated to reach a staggering 3–4 billion pounds in the United States [3], while China contributes over 1.5 billion pounds [4]. Nevertheless, their industrial-scale applications are somewhat restricted, primarily confined to animal feed, and their ultimate fate typically involves incineration or landfill disposal [5]. Feathers exhibit remarkable accessibility, cost-effectiveness, renewability, and biodegradability, rendering them a highly reliable feedstock for biopolymers, which are anticipated to possess analogous characteristics to polyamides [6]. In the realm of contemporary scientific exploration, diligent scholars have been meticulously exploring novel avenues for the utilization of feather-based materials. These materials, with their inherent properties, have shown great promise in diverse domains, including but not limited to sustenance or biodegradable encasements [4,7], ingestible membranes [8], biosorbents [9], and other composites [10]. Nevertheless, it is imperative to acknowledge that biodegradable packaging exhibits certain constraints pertaining to its thermal stability, resistance to aqueous environments, mechanical attributes, and economic viability [11]. Keratins exhibit a remarkable abundance of intermolecular and

* Corresponding author.
E-mail address: mkamruzzamandu81@gmail.com (Md. Kamruzzaman).

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intramolecular cystine cross-links, thereby setting them apart from other fibrous proteins, including collagen and myofibrillar proteins [12]. As a result of the extensive cross-linking of disulfide bonds and the densely packed β-sheet conformation within the polypeptide chain, the solubilization and manipulation of keratin in conventional solvents pose considerable challenges [6]. The primary drawback associated with the use of biodegradable feather keratin (FK) film resides in its inherent brittleness and suboptimal toughness, particularly when lacking any plasticizing agents. The enhancement of these properties can typically be achieved through the processes of blending and cross-linking. The incorporation of keratin into the PVA matrix has been observed to yield enhancements in the mechanical characteristics of PVA-based films [13].

Polyvinyl alcohol (PVA) exhibits remarkable characteristics such as excellent compactness, elevated crystallinity, robust adhesion, non-toxicity, and a favorable affinity towards water molecules [14]. The PVA macromolecule exhibits a substantial abundance of hydroxyl functional groups, rendering it remarkably hydrophilic in nature. The incorporation of keratin within PVA matrices exhibits a remarkable potential to amend the architectural arrangement, augment the mechanical characteristics of the film, and enhance its thermal stability and hydrophobicity [15].

In recent years, there has been a notable surge in research endeavors centered around the synthesis of polyvinyl alcohol (PVA)-derived biopolymers, owing to their immense potential for utilization in diverse eco-friendly applications [16]. The incorporation of natural polymers, such as proteins, into the polyvinyl alcohol (PVA) matrix has been employed to improve the processability of polypeptides and introduce specific functional groups that can imitate the inherent ability of the extracellular matrix to facilitate cellular interactions [17,18]. Furthermore, the significant pertinence of proteins as an instructive biomaterial has been extensively documented in the scientific literature [19]. In accordance with previous investigations, it has been elucidated that keratin exhibits a pronounced hydrophilic nature, thereby enhancing its mechanical prowess and biodegradability when compared to alternative protein counterparts such as zein and gelatin [20].

Given the remarkable inherent characteristics exhibited by keratin, it is indeed an undeniable fact that incorporating keratin into the PVA matrix would undeniably enhance the overall physical attributes of PVA. Based on the current body of scientific literature, it is evident that there is a dearth of comprehensive research pertaining to bioplastics derived from the combination of polyvinyl alcohol (PVA) and keratin. Henceforth, in this investigation, biopolymers comprising keratin and PVA were synthesized into composite films via the solution casting technique, with a keen focus on exploring the influence of varying concentrations on the inherent characteristics of PVA/keratin blended films.

2. Materials and methods

2.1. Materials

The utilized experimental reagents in this investigation comprised of sodium chlorite ($NaClO_2$), sodium sulfide (Na_2S), sodium hydroxide (NaOH), polyvinyl alcohol (PVA), hydrochloric acid (HCl). The aforementioned reagents were purchased from Sigma-Aldrich and utilized in the experimental procedure without undergoing any supplementary purification steps. The laboratory-prepared distilled water was employed in all of the experiments.

2.2. Methods

Duck feathers, obtained from a nearby duck farm, underwent multiple aqueous washes utilizing a neutral soap solution and 0.5 % (w/v) sodium chlorite in order to effectively eliminate any impurities present at room temperature (25 ± 2 °C) for 30 min. The clean feathers were dried in an oven at 80 °C for 5 h. The dried feathers were chopped into small pieces and subjected to dissolution in a solution containing 0.1 M sodium sulfide and 0.5 M sodium hydroxide while being vigorously agitated for 6 h at a temperature of 80 °C. Following the filtration step, the solution underwent centrifugation at a speed of 10,000 rpm for 5 min. The filtrate was obtained employing filter paper, and the pH was adjusted to 4.2 by the addition of 3 M hydrochloric acid. Subsequent to the keratin precipitation, it was subjected to centrifugation at 10,000 rpm for 10 min, followed by drying in an oven set at a temperature of 90 °C to obtain keratin particles. To create bioplastic film, it was then dissolved in 1 M sodium hydroxide and combined with PVA solution at various concentrations. The mixture was heated to 90 °C for 2 h while being continuously stirred. After cooling, it was placed into a Petri dish and dried for 16 h at 80 °C. Schematic representation of keratin synthesis and bioplastic film fabrication is illustrated in Fig. 1. The bioplastic film was labeled with the following labels (Table 1).

2.3. Characterization techniques

Infrared spectroscopy, also known as IR spectroscopy, is a highly ubiquitous spectroscopic technique employed for the examination of functional groups and bond formations within a given material. The prepared sample is analyzed using the FTIR (Ir Prestige-21, Shimadzu, Japan) instrument, which is equipped with an ATR (Attenuated Total Reflectance) accessory. For precise identification and characterization of molecular vibrations, the spectral range was set at 4000 to 500 cm^{-1} at a scanning rate of 16 scans with a resolution of 4 cm^{-1}. The thermogravimetric analysis (TGA) was performed using a SII TG/DTA 6200 instrument manufactured in Japan. The analysis was carried out by subjecting the sample to a temperature range from ambient temperature to 800 °C, with a heating rate of 10 °C/min. The experiment was conducted under a nitrogen environment, with a flow rate of 20 ml/min. The samples were subjected to morphological analysis using scanning electron microscopy (SEM) with a JEOL6400 SEM from Japan, operating at an accelerating voltage of 25 kV. Gravimetric measurements were employed to assess the water absorption and degradation properties, following the previously documented methodology [21]. In a standard protocol, the specimens underwent incubation in distilled water at a temperature of 37 °C, following which their masses were assessed following a 24 h period of immersion. Preceding the weighing process, the excess water present on the surface was gently removed using absorbent tissue paper. The quantification of water uptake was assessed in relation to the mass of the sample under investigation, and subsequently determined using the subsequent mathematical expressions (1) and (2).

$$Water\ absorption = \frac{W_2 - W_1}{W_2} \times 100\% \quad (1)$$

$$Degradation = \frac{W_1 - W_2}{W_1} \times 100\% \quad (2)$$

Where, W_1 = Initial weight of the bioplastic films; W_2= Final weight of the bioplastic films.

In order to assess the potential cytotoxicity of the bioplastic film, a comprehensive cytotoxicity analysis was performed. The cytotoxic effect was assessed within the controlled laboratory environment of the Centre for Advanced Research for Science (CARS) lab, located at the esteemed University of Dhaka. In a nutshell, the Vero cell line, which is derived from the kidney epithelial cells of an African green monkey, was cultured in DMEM (Dulbecco's Modified Eagles' medium) supplemented with 1 % penicillin-streptomycin (1:1), 0.2 % gentamycin, and 10 % fetal bovine serum (FBS). A population of cells (7.5 × 104/500 μL) was introduced onto a 24-well plate and subjected to incubation at a temperature of 37 °C in an environment enriched with 5 % CO_2. On the subsequent day, the media was carefully extracted, and subsequently, 400 μL of pristine media along with 100 μL of sterilized samples were

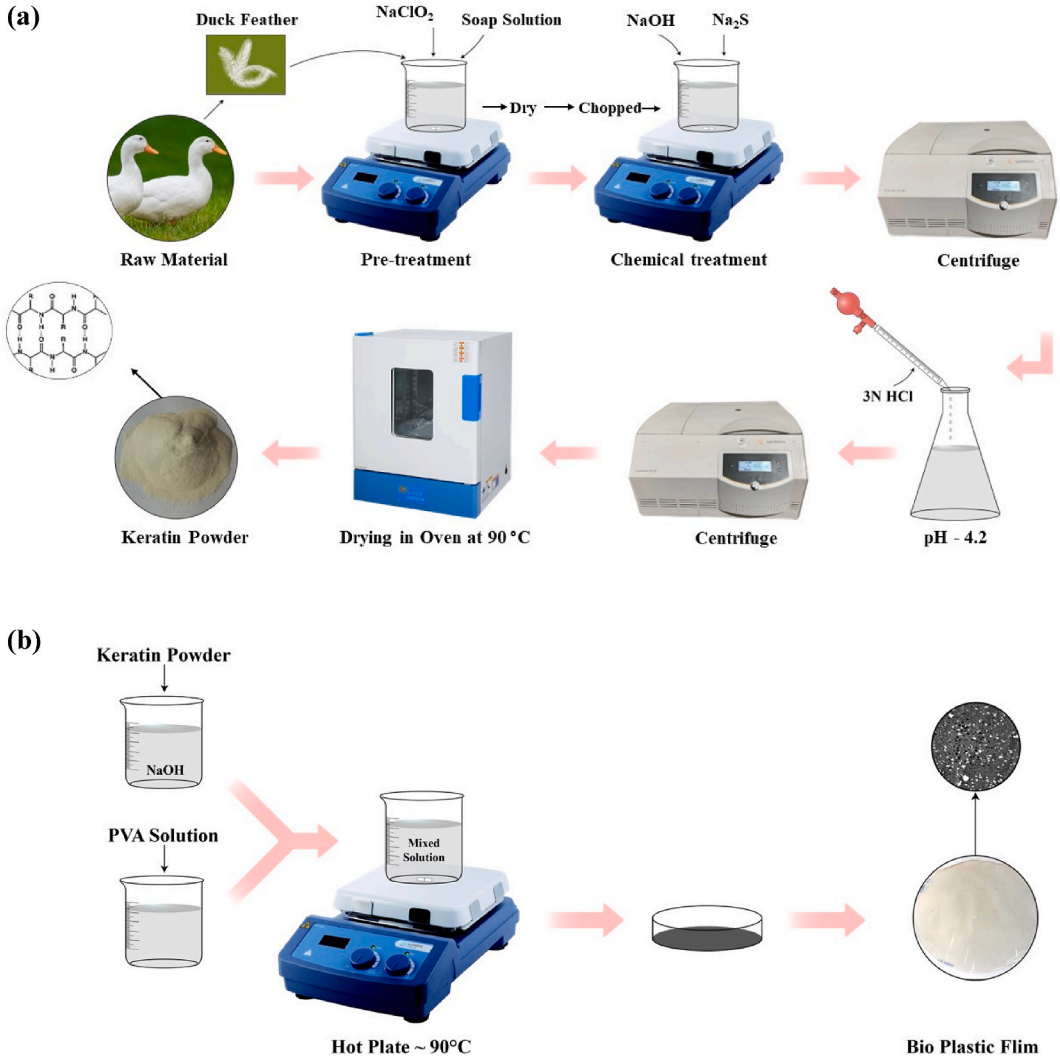

Fig. 1. Schematic illustration of (a) keratin and (b) bioplastic film synthesis.

Table 1
Labelling of bioplastic films.

Sample name	PVA (wt.%)	Keratin (wt.%)
2 % PVA	2	0
P5	5	0
P2K0.05	2	0.05
P5K0.05	5	0.05
P10K0.05	10	0.05
P5K0.025,	5	0.025
P5K0.075	5	0.075
P5K0.10	5	0.10
P5K0.15	5	0.15
P5K0.25	5	0.25

meticulously introduced into each individual well. The mechanical properties including elongation at break (%), tensile strength (MPa), and Young's modulus (GPa) were analyzed using a universal testing machine (UTM) in accordance with standard procedures for thin film materials (ASTM D882-12). Cytotoxicity was assessed utilizing an inverted light microscope for duration of up to 48 h. Each sample was subjected to well duplication for experimental purposes.

3. Result and discussion

Keratin was effectively extracted from waste duck feathers. After alkaline reduction, followed by appropriate pH adjustment and drying, the extraction process resulted in a keratin yield of approximately 79 %, calculated based on the dry weight of the initial feather material. This high yield reflects the efficiency of the extraction approach and is consistent with values reported in similar studies involving poultry feathers. The results highlight the potential of waste duck feathers as a valuable and sustainable source of keratin for use in biopolymer development.

3.1. FTIR analysis

The Fourier Transform Infrared (FTIR) spectrum acquired from each of the samples is depicted in Fig. 2. The FTIR analysis of keratin is anticipated to exhibit distinctive peaks that correspond to significant functional groups such as -CO-NH-, -NH_2, -CNH, and -C-H. The spectral feature observed at approximately 3287 cm^{-1} can be attributed to the stretching vibrations of hydrogen-bonded -N-H and -O-H groups present in the amide functional group as well as water molecules that have been absorbed. The relatively subdued peak observed in the vicinity of 2920 cm^{-1} denotes the stretching vibrations of the -C-H and -N-H functional groups. A peak at approximately 1746 cm^{-1} represents the C=O stretching vibration of the amide I group. The detected peak at 1321 cm^{-1} corresponds to the -CNH moiety, involving stretching vibrations of the -C-N- and -C-C- groups as well as a bending vibration of the -N-H group (amide III region). The bending vibration of the -CH_2 moiety was

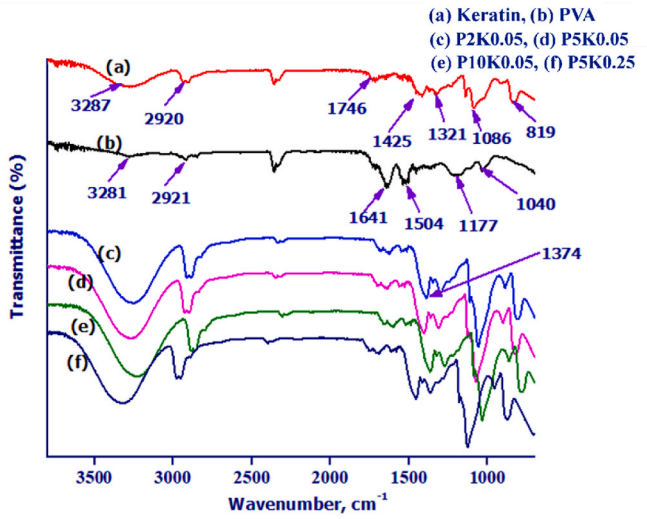

Fig. 2. FTIR of the bioplastics.

observed at a wavenumber of 1425 cm^{-1} [22]. The prominent and distinct peak observed at 1504 cm^{-1} is assigned to N–H bending and C–N stretching, characteristic of the amide II group [23]. The medium-intensity sharp peaks observed at 1086 and 819 cm^{-1} are indicative of the stretching vibration of the -C-N- functional group. The FTIR results exhibit distinct peaks corresponding to amide -N-H, -C=O, -C-N-, and -CNH functionalities, providing confirmation of the presence of amino acids, which serve as the fundamental units in the formation of peptide groups within the keratin protein structure.

Fig. 2 (b) illustrates the FTIR spectra of Polyvinyl Alcohol (PVA). The primary spectral maxima of PVA were detected at wavenumbers of 3281, 2921, 1641, 1504, 1177, 1040, and 839 cm^{-1}. The observed peaks have been attributed to the vibrational modes of various functional groups present in the sample. Specifically, the peaks correspond to the stretching vibration of the O–H bonds in the hydroxyl group, the asymmetric stretching vibration of the CH_2 moiety, the bending vibration of the C–H bonds in the CH_2 group, the deformation vibration of the C–H bonds, the stretching vibration of the C–O bonds in the acetyl groups, and the stretching vibration of the C-C bonds. These assignments are in accordance with previous studies [24].

Fig. 2 (c), (d), (e), and (f) display the FTIR spectra obtained for polyvinyl alcohol (PVA) combined with keratin film. The spectral data that was observed indicates the presence of different peaks that are connected with the intrinsic characteristics of both polyvinyl alcohol (PVA) and keratin. Significantly, an observable modification in the bonding configuration is evident, specifically in the absorption peaks of keratin at 1504 cm^{-1}, which have seen a displacement to 1374 cm^{-1}. The observed shift in this context indicates a chemical interaction, specifically the presence of hydrogen bonding between the keratin and PVA film. A Possible mechanism of PVA/Keratin Bioplastic Film is given below in Fig. 3.

3.2. SEM analysis

Fig. 4 (a) depicts the scanning electron microscopy (SEM) image of polyvinyl alcohol (PVA), while Fig. 4 (b) demonstrates the incorporation of keratin into PVA (P5K0.05). In the representative bioplastic film, the chromatic manifestation corresponds to the keratinaceous component, while the contrasting hue signifies the presence of PVA. The SEM image of pure PVA exhibits highly compatible morphologies devoid of cavities, edges, and holes. Furthermore, the bioplastic film demonstrates commendable interconnection between its constituents, which can be attributed to the existence of chemical interactions between keratin and PVA [25]. Hence, the PVA facilitated the formation of a uniform incorporation exhibiting evident plasticization within the keratin matrix, devoid of any segregation and displaying singular phase morphology. The SEM analysis revealed a largely homogeneous matrix indicative of singular-phase morphology, with a few dispersed undissolved keratin particles that did not disrupt the continuity or plasticized nature of the PVA-keratin matrix. The existence of empty micro voids could potentially be attributed to the improved dispersion of the plasticizer within the polymer matrix, particularly at lower plasticizer concentrations. As per the investigation [26], the affinity for the formation of vacant voids and phase segregation exhibits a direct correlation with the concentration of PVA. As a consequence of this phenomenon of dispersion, it is plausible that the thermal stability and mechanical properties of the film could potentially experience enhancement.

3.3. TGA analysis

The thermogravimetric analysis (TGA) technique was employed to investigate the thermal stability characteristics of the polyvinyl alcohol (PVA) based bioplastic film. The graphical representation elucidates that the bioplastic derived from PVA, with varying concentrations of keratin, exhibits a consistent pattern of mass reduction. The experimental results indicate a decrease in the weight of various samples as the temperature is elevated (Fig. 5). The thermal profiles of the samples, exhibiting distinct weight losses, are presented in Table 2.

The thermal stability of keratin exhibits an enhanced profile when compared to PVA and various concentrations of keratin. Based on the observed data, it can be inferred that the incorporation of keratin within the film matrix resulted in an enhancement of its thermal stability. The observed phenomena can be elucidated by the inherent ability of carboxyl and amide groups present in keratin to establish hydrogen bond crosslinking interactions with the hydroxyl groups of PVA. This intermolecular bonding effectively restricts the mobility of polymer

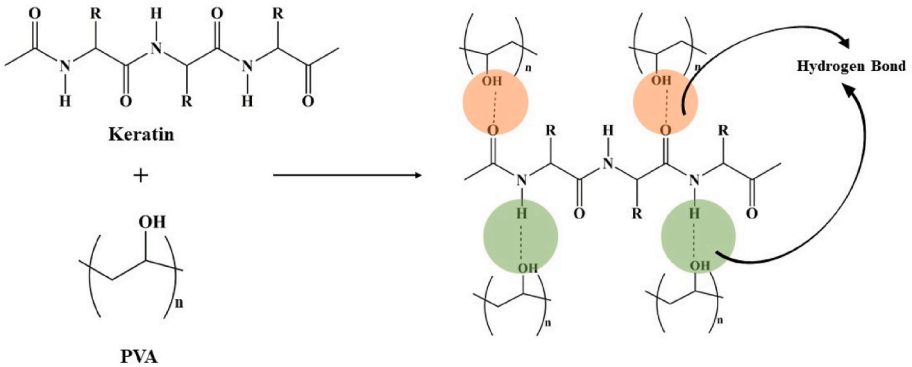

Fig. 3. Illustration of possible reactions and interactions among keratin/PVA biodegradable film.

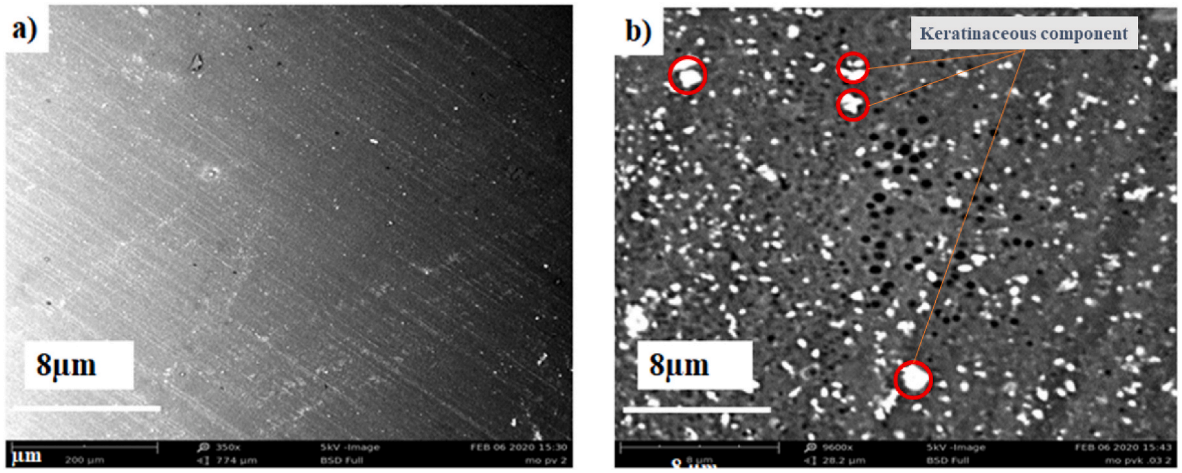

Fig. 4. SEM micrograph of a) Pure PVA b) PVA + Keratin (P5K0.05).

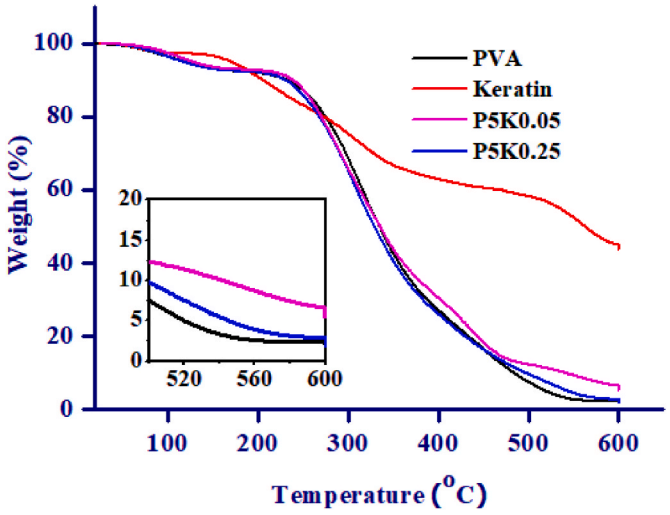

Fig. 5. TGA curve of PVA, Keratin and bioplastic film made with different concentration of keratin.

Table 2
The weight of differential TGA curve of various samples at temperature 600 °C

Sample name	Weight retained after 600 °C
PVA	2.02 %
Keratin	43.9 %
P5K0.05	5.44 %
P5K0.25	2.84 %

chains during the thermal treatment process [27]. The TGA curves depicted in Fig. 5 exhibit a triphasic weight loss pattern across all the examined samples. During the initial phase, a discernible reduction in mass, typically below 10 wt%, is observed within the temperature range of ambient conditions up to 200 °C. This phenomenon can be attributed to the evaporation of moisture that has been absorbed by the sample [28]. During the subsequent phase, the specimens exhibited a pronounced and swift decomposition within the temperature range of 250–475 °C. This decomposition process resulted in a significant mass reduction of 17–85 wt%, which can be attributed to the decomposition of glycerol and PVA [29]. Throughout the entire spectrum of temperature ranges, the P5K0.05 exhibited a discernibly lower magnitude of mass reduction in comparison to the other specimens under investigation. This observation indicates an enhanced resistance to thermal degradation for the cross-linked film, which can be attributed to the incorporation of keratin within its structure. The observed augmentation in thermal stability can likely be ascribed to the establishment of robust intermolecular linkages, signifying that the intermolecular interactions between PVA and keratin become more pronounced as the temperature rises, surpassing those of the other samples. This phenomenon is likely attributable to the intensified efficacy of keratin's cross-linking process when subjected to elevated temperatures [30].

3.4. Mechanical test

Fig. 6 exhibits the elongation of break of the prepared bioplastic film under two distinct conditions: (a) a consistent keratin concentration of 0.05 %, and (b) a constant PVA concentration of 5 %. Based on the observations depicted in Fig. 6 (a), it is apparent that the elongation at break of the bioplastic film exhibits a steady and continuous increase, ultimately reaching its peak value of 191.36 % relative to the reference value, while maintaining a constant keratin percentage. The observed phenomenon can be attributed to the inherent thermoplastic nature of PVA, which results in a higher elongation at break [31]. In Fig. 6(b), it is observed that the elongation at break of the bioplastic film, which has been prepared with a constant PVA concentration, exhibits a consistent decrease as the percentage of keratin is increased. The observed phenomenon can potentially be attributed to the inherent stiffness of the keratin particle and the non-uniform dispersion of the particle within the PVA film. As the concentration of keratin particles is increased, there is a propensity for them to undergo agglomeration [32].

The measurement and evaluation of tensile strength is a critical and extensively conducted procedure in the realm of material engineering, particularly when considering the utilization of asserted materials in structural applications. Based on the observations presented in Fig. 6 (c), it can be inferred that the quantity of PVA has a direct impact on the tensile characteristics of the bioplastic film. The observed trend in the tensile strength of the film can be characterized as an initial increase followed by a subsequent decrease as the PVA content is progressively increased. The observed phenomenon can be ascribed to the inherent high tensile strength exhibited by PVA. However, as the PVA concentration in the film is elevated, it undergoes aggregation, leading to a consequential decline in its tensile strength. In accordance with the findings depicted in Fig. 6 (d), it can be observed that the progressive augmentation of keratin percentage fails to create any discernible impact on the tensile strength of the film. The highest value of tensile strength is attained at a keratin concentration of 0.075 wt%.

The Young's modulus is a fundamental property that characterizes

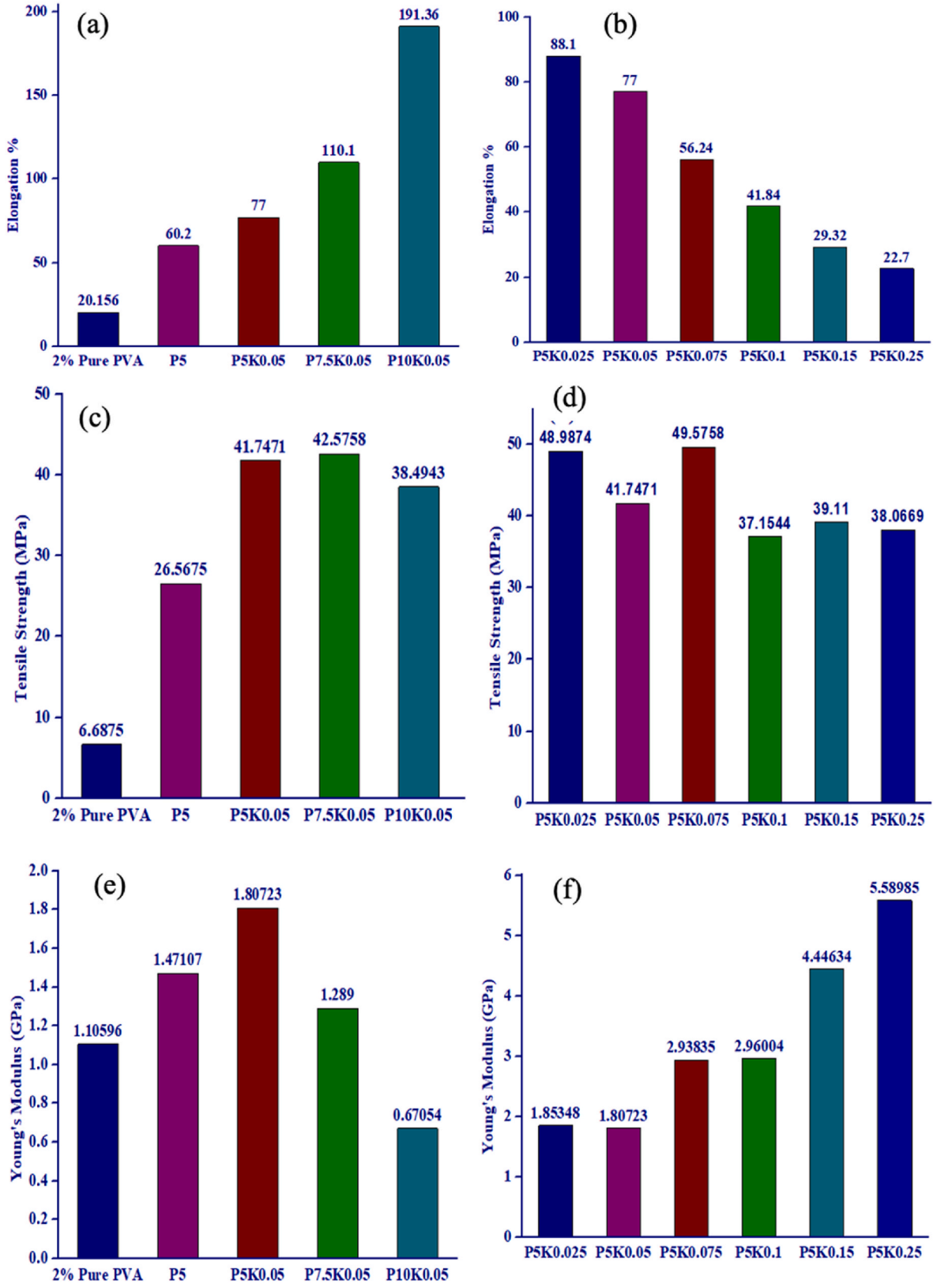

Fig. 6. Elongation % of bioplastic film where a) concentration of PVA is varied with 0.05 %Keratin, and b) concertation of keratin is varied with 5 %PVA; Tensile strength of bioplastic film where c) concentration of PVA is varied with 0.05 %Keratin, and d) concertation of keratin is varied with 5 %PVA; Young's Modulus of bioplastic film where e) concentration of PVA is varied with 0.05 %Keratin, and f) concertation of keratin is varied with 5 %PVA.

the mechanical behavior of a material, specifically its resistance to deformation under applied stress. It quantifies the material's ability to withstand bending or stretching, providing insight into its stiffness. In Fig. 6 (e), the Young's Modulus of the film is depicted at a consistent concentration. The experimental findings demonstrate a positive correlation between the Young's Modulus and the incorporation of PVA in the material matrix, up to a concentration of 5 wt%. The observed trend indicates a decrease in Young's modulus as the PVA content is increased. In Fig. 6 (f), the Young's Modulus of the film is depicted while maintaining a constant PVA content. In this particular scenario, it can be observed that the Young's Modulus of the film exhibits an upward trend as the quantity of keratin powder is augmented. The observed phenomenon could potentially be attributed to an elevated concentration of keratin particles, known for their inherent rigidity.

Based on the aforementioned mechanical tests, it can be inferred that the P5K0.05 formulation offers the most balanced and optimal mechanical performance for the intended application.

3.5. Water absorbance and degradation

The degradability of polymers is an essential characteristic that significantly impacts their suitability for various applications. Although multiple standardized methods such as ISO 17556, ASTM D5988, and ASTM D6400 exist for assessing polymer biodegradability under soil and composting conditions, the choice of method often depends on the specific environmental context and the material's intended application. Various studies have employed different methodologies, including the enzyme approach [33], the microbiological method [34], and the soil burial method [35]. Furthermore, the measurement of biodegradability is subject to variation among different indices, even when employing identical methodologies. The fundamental characteristics of biodegradable materials lie in their water absorption capacity and degradability. A notable disparity was seen in the water absorption capacity of the PVA/keratin blend films. These findings align with the outcomes reported in Ref. [33]. The data presented in Fig. 7 (a) and (b) provide unambiguous evidence that the extent of degradation is significantly greater in films with higher PVA content, likely due to the water-soluble and biodegradable nature of PVA, which promotes faster disintegration under soil burial conditions. The incorporation of keratin in all concentrations resulted in a reduction in the water solubility of the films. This can be attributed to the presence of keratin layers, which serve as a hindrance to the diffusion of water into the films [36]. The comparison of the variation in polyvinyl alcohol (PVA) and keratin demonstrates that degradation is significantly more evident under conditions of high-water sorption. The hydroxyl groups of polyvinyl alcohol (PVA) have the ability to establish robust hydrogen bonds with the carboxyl and amide groups found in keratin. Consequently, this enhances the molecular connections, promotes the cohesiveness of the biopolymer matrix, and reduces its susceptibility to water. P5K0.05 demonstrated a notable capacity for water absorption as well as the most substantial reduction in weight.

3.6. Cytotoxicity test

The invitro cytotoxicity assessment (Fig. 8) of the bioplastic was conducted utilizing the Vero cell line, supplemented with a combination of 1 % penicillin-streptomycin (1:1), 0.2 % gentamycin, and 10 % fetal bovine serum (FBS). Based on the data presented in Table 3, it is evident that the bioplastic films prepared exhibit a lack of cytotoxicity. The viability of the Vero cell line exhibits a remarkable survival rate exceeding 95 % across all examined samples, indicating that the observed outcomes are not attributable to the cytotoxicity of the films. The observed toxicity of approximately 5 % in the control sample may be attributed to the potential existence of impurities.

4. Conclusion

In this investigation, a biocompatible and environmentally friendly bioplastic was effectively synthesized through the utilization of keratin derived from duck feathers, demonstrating its potential as a biodegradable material in biomedical applications. The Fourier Transform Infrared (FTIR) spectra exhibited distinct peaks indicative of the presence of PVA and keratin within all of the composite samples. Notably, the peak observed in the wavenumber range of 2900–2950 cm^{-1} signifies the occurrence of a complex interaction reaction between PVA and keratin. The observed mechanical properties, specifically the elongation at break, exhibited a positive correlation with the concentration of PVA in the prepared films. The tensile strength and Young's modulus were observed to be enhanced as a result of the reinforcement of keratin. The optimal film composition, yielding the most favorable mechanical properties, was determined to be P5K0.05 (PVA 5 % - Keratin 0.05 %). Additional characterization techniques, namely thermogravimetric analysis (TGA) and scanning electron microscopy (SEM), exhibited favorable concurrence with the aforementioned outcome. The results of the water absorption and degradation tests, in conjunction with the cytotoxicity test, have demonstrated that the bioplastic films prepared in this study exhibit biodegradability and non-toxicity. Our investigation has determined that the optimal composition for the bioplastic film is P5K0.05. This particular composition holds promise for various applications in the biomedical field as well as in packaging, where the

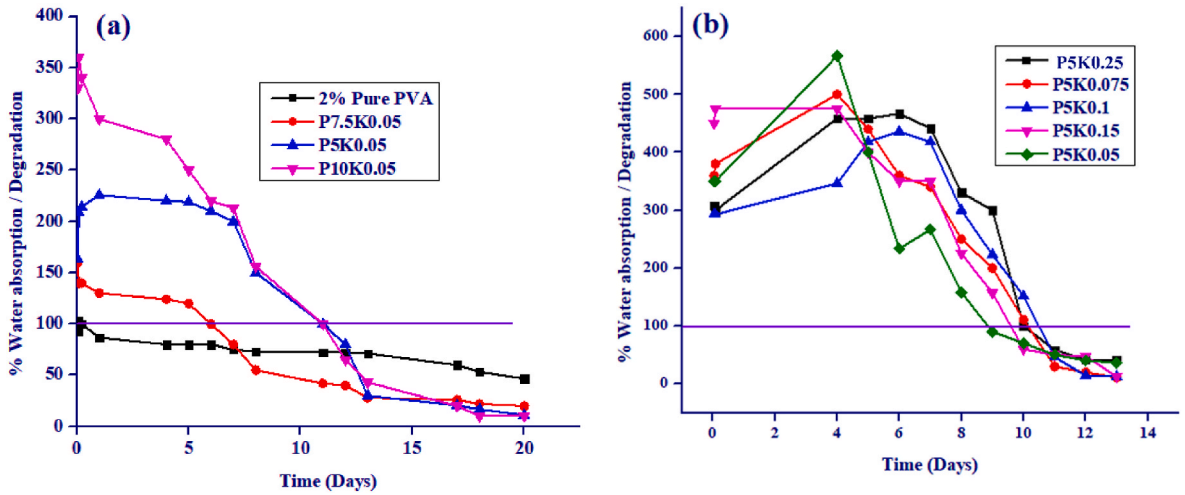

Fig. 7. Degradation curve of bioplastic film where (a) concentration of PVA is varied with 0.05 %Keratin, and (b) concertation of keratin is varied with 5 %PVA.

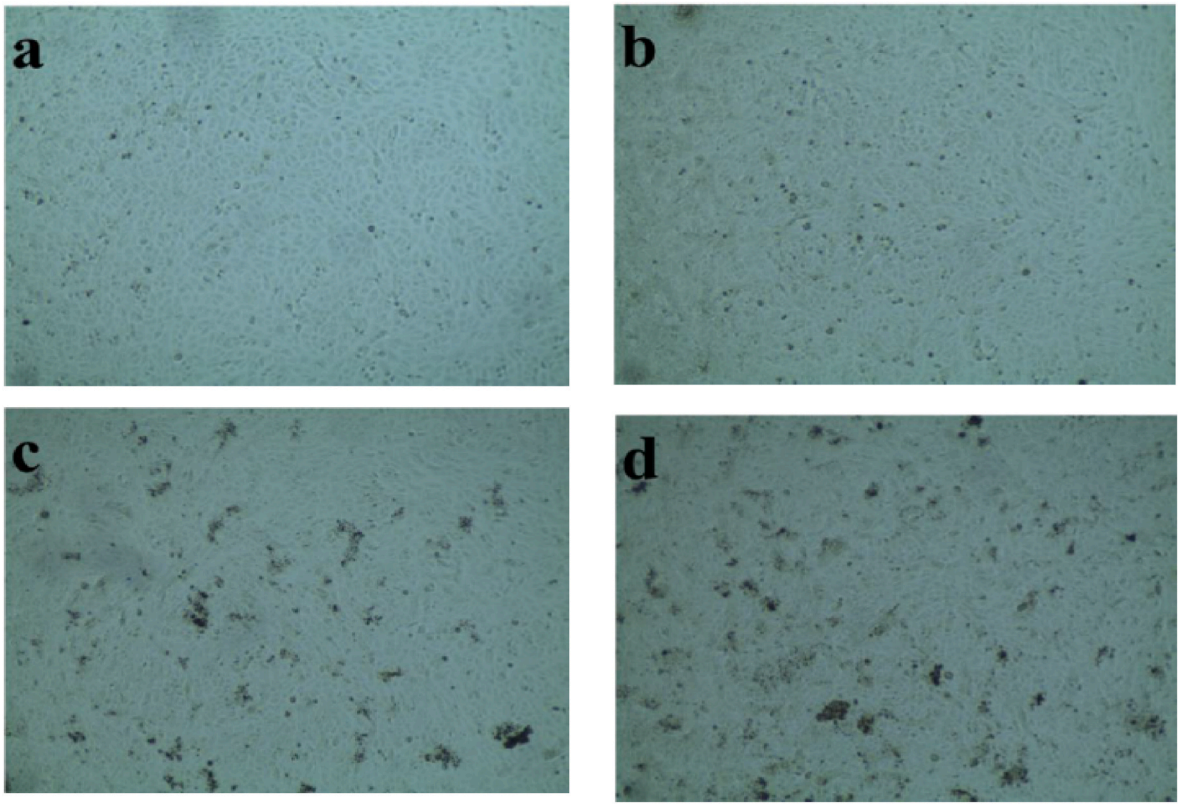

Fig. 8. Images of cytotoxic effect of bioplastics with control (distilled water); a) Vero cells without control, b) Control, c) B5, d) BK10.

Table 3
Results of Cytotoxic effect of bioplastic films in Vero cell line.

Sample name	Survival rate	Remarks
Without control	100 %	
With control	>95 %	No cytotoxicity
B5 (P5K0.05)	>95 %	No cytotoxicity
B10 (P5K0.25)	>95 %	No cytotoxicity

material's biodegradable, mechanical toughness and non-toxic properties are essential.

CRediT authorship contribution statement

Md. Lawshan Habib: Writing – review & editing, Investigation, Data curation. **Md. Hanif Munshi:** Writing – original draft, Validation, Resources, Formal analysis, Data curation, Conceptualization. **Md. Kamruzzaman:** Supervision, Project administration, Investigation, Funding acquisition, Conceptualization. **Tama Baul:** Resources, Methodology, Formal analysis, Data curation. **M. Mehedi Hasan:** Visualization, Supervision, Software, Project administration.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: There are no other relationships to declare If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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