COMPOSITES BASED ON POLYVINYL ALCOHOL, CHITOSAN, AND CURCUMIN FOR WOUND HEALING APPLICATIONS

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Abstract

Natural polymers, like chitosan, collagen, and alginate, offer promising solutions for wound healing. Derived from natural sources, they exhibit biocompatibility and bioactivity, promoting tissue regeneration. These polymers can form scaffolds or dressings that accelerate wound closure while reducing infection risks. Their inherent properties make them promising options in the quest for effective wound care materials.

In this work, composites based on polyvinyl alcohol (PVA), chitosan (Chi), and curcumin (Cur) were prepared. PVA, a synthetic water-soluble polymer, finds extensive use in biomedical and wound-healing applications. It is approved by the U.S. FDA for cosmetic, medical, and wound healing products. Chi, a polysaccharide, is widely used in biomedicine and possesses antibacterial properties. Both PVA and chitosan are biocompatible and exhibit good filming characteristics. Curcumin (Cur) with antibacterial and antioxidant properties is being explored for regenerative medicine. PVA, chitosan, and curcumin were blended. The structure was studied by FTIR, microscopic observations were done with optical and scanning electron microscopes, and the mechanical properties were assessed. FTIR revealed component interactions, while microscopy showed a flat film surface. The polymeric blend (PVA/Chi/Cur) had a Young's modulus of 1.49 GPa, tensile strength of 47.69 MPa, stress value of 8.39 N, and 35.34% elongation at break. These properties make the blend suitable for consideration in wound healing applications.

Keywords: *polyvinyl alcohol, chitosan, curcumin, polymer blends, wound healing*

Introduction

Poly(vinyl alcohol) (PVA) is a semi-crystalline and water-soluble polymer [1]. PVA exhibits limited solubility in ethanol and is insoluble in other organic solvents [2]. The preparation of poly(vinyl alcohol) is achieved through the hydrolysis of polyvinyl acetate and can be easily degraded by biological microorganisms [3]. PVA is considered ideal for wound dressings due to its non-toxicity, biodegradability, and low cost [4]. The properties of poly(vinyl alcohol) are highly dependent on the acetyl group content in the initial polymer [5]. The applications of poly(vinyl alcohol) are determined by its degree of hydrolysis [6]. Tavakoli et al. utilized poly(vinyl alcohol) with a degree of hydrolysis of 99.9% for wound healing applications [7]. Murphy et al. employed poly(vinyl alcohol) with degrees of hydrolysis of 88% and 98%. It has been suggested and recommended to use poly(vinyl alcohol) with a higher degree of hydrolysis for wound healing applications [8]. PVA wound dressings are non-adhesive, making them suitable for easy dressing changes without causing new wound injury [9].

Chitosan is a polysaccharide of marine origin [10] and is often described as a natural cationic polymer with a positive charge [11,12]. Chitosan is derived from chitin, a fundamental component of crustacean shells, through chemical modification [13]. Chitin is insoluble in water due to extensive hydrogen bonding [14], while chitosan can be dissolved in weaker acids, like acetic acid, to form membranes and fibers [15]. Chitosan contains amine functional groups, and these groups can be chemically modified, making Chi very useful for biomedical applications [16]. Chitosan is widely applied in the pharmaceutical and biomedical fields as it has interesting properties [17], such as high biocompatibility, anticancer properties, blood clotting facilitation, and coagulation effects [18].

Wound healing involves various phases, such as inflammation, proliferation, and tissue remodeling, making it a complex process requiring specialized treatments [19]. A good wound dressing should facilitate gaseous exchange, maintain wound surface moisture, and be able to remove extra wound fluid or exudates [20]. The obvious reason for using chitosan in wound healing is its ability to enhance healing and skin restoration [21,22], and it has been reported as highly applicable in regenerative medicine [23]. Chitosan also aids in blood coagulation and adheres to red blood cells due to its hemostatic nature [24,25].

The use of chitosan as a standalone wound healing material may lead to loss of strength after absorbing the wound exudates, resulting in decomposition. To prevent disintegration, it is often combined with other compounds, such as synthetic polymers like poly(vinyl alcohol) [26-28]. A significant limitation of using chitosan alone in wound dressings is its insolubility in water [29]. Chitosan is frequently blended with PVA to enhance the antibacterial properties of the resulting hydrogel [30].

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Curcumin, a yellow-colored polyphenol, is naturally found in the rhizome of *Curcuma longa* [31]. It is also known as difluoromethane [32,33]. Curcumin is hydrophobic and can be dissolved in ethanol, acetone, and dimethyl sulphoxide [34]. It has antioxidant, anticarcinogenic, anti-inflammatory, and anticoagulation properties. Curcumin shows a promising role in wound healing [35,36], primarily by participating in tissue remodeling, collagen deposition, and tissue formation [37]. Fianza et al. noted its effectiveness in the inflammation stage of wound healing due to its role in reducing reactive oxygen species [38]. Curcumin is also capable of scavenging free radicals [39], as it can share electrons or hydrogen atoms from its phenolic sites. Additionally, it acts as a lipophilic compound [40]. Li et al. utilized chitosan nanoparticles with curcumin, improving the wound healing process in diabetic rat models [41]. Alven et al. reported that wound dressings containing curcumin improved mechanical properties and enhanced wound healing [42]. Akbik et al. emphasized that curcumin plays a vital role in all stages of the wound healing process [43]. Rezaei et al. suggested that blending curcumin with polymeric solutions is the best approach to control its release in biomedical applications [44]. The use of curcumin is limited due to its poor water solubility and photosensitivity [34], with a substantial portion of orally administered curcumin passing undigested through the gastrointestinal system [45,46].

In this study, polymeric blends of poly(vinyl alcohol), chitosan, and curcumin were prepared. We analyzed the mechanical properties of the resulting polymeric blend and conducted microscopic analysis of the polymeric film. Fourier Transform Infrared (FTIR) spectra were recorded to investigate functional groups. Chitosan and poly(vinyl alcohol) were incorporated into the film, indicating potential wound healing properties. Furthermore, curcumin, with its antioxidant properties, may improve wound healing. Therefore, combining wound healing materials such as poly(vinyl alcohol) and chitosan with curcumin may offer new materials for biomedical applications with enhanced properties.

Materials and Methods

Poly(vinyl alcohol) (363065, CAS:9002-89-2, MW: 146,000-186,000), and chitosan (448869, CAS:9012-76-4, MW: 50,000-190,000) were obtained from Sigma-Aldrich, Darmstadt, Germany. Curcumin (GP8291, CAS: 458-37-7, MW: 368.39) was received from Glentham Life Sciences, Corsham, United Kingdom. Ethanol (Cat. 32294, CAS: 64-17-5, MW: 46.07, 96%) was provided by Honeywell, Riedel-de Haen, Seelze, Germany. Acetic acid (CAS:64-19-7, MW: 60.05, 99.9%) from STANLAB, Lublin, Poland, was used.

Sample preparation

At the beginning, the following solutions were prepared: 5% polyvinyl alcohol (PVA) in water, 2% chitosan (Chi) in acetic acid, and 5 mg curcumin (Cur) in 5 mL of ethanol. PVA/Chi polymeric blend was formulated in a 50:50 proportion, next 2% of dissolved curcumin was added to the polymeric blend. Polymeric films of PVA, Chi, and polymeric blend (PVA/Chi/Cur) were prepared by solvent casting.

Microscopic analysis

Microscopic analysis of the surface of the polymeric films was carried out using a Motic microscope (SMZ-171, China) with 0.75 resolution and with a scanning electron microscope (SEM; LEO, Electron Microscopy Limited, Cambridge, UK).

Fourier Transform Infrared Spectroscopy (FTIR)

Fourier Transform Infrared (FTIR) spectra of the polymeric films and curcumin powder were analyzed using Nicolet iS10 furnished with an ATR device (Thermo Fisher Scientific, Waltham, MA, USA). The spectrum was recorded in the 400-4000 cm^{-1} range with a resolution of 4 cm^{-1} following 64 scans. Omnic 2009 software was used for spectra processing.

Mechanical properties testing

Mechanical properties of the PVA, Chi, PVA/Cur, PVA/Chi/Cur films were analyzed using Zwick and Roell 0.5 testing machine combined with testXpert II 2017 software. Seven samples of each type were investigated. The initial test parameters were: 0.1 MPa preload, 5 mm/min preload speed, and 50 mm/min test speed.

Statistical Analysis

ANOVA test was used for statistical analysis. The variance was checked by following the standard deviation results.

Results and Discussions

Microscopic analysis of polymeric films is presented in FIG. 1. FIG. 1a illustrates the microscopic image of PVA and clearly shows a smooth surface. In FIG. 1b PVA and Cur have been mixed homogeneously. In this figure, the curcumin effect can be seen in the polymeric blend, as it changed the color of the polymeric blend to a pale-yellow color. FIG. 1c represents the polymeric blend (PVA/Chi/Cur). It can be noticed that PVA, Chi, and Cur are compatible in the polymeric blend and are homogeneously mixed. This uniformity or homogeneity is achieved due to the stirring of polymeric solutions for 24 h and the interaction between PVA and chitosan via hydrogen bonds.

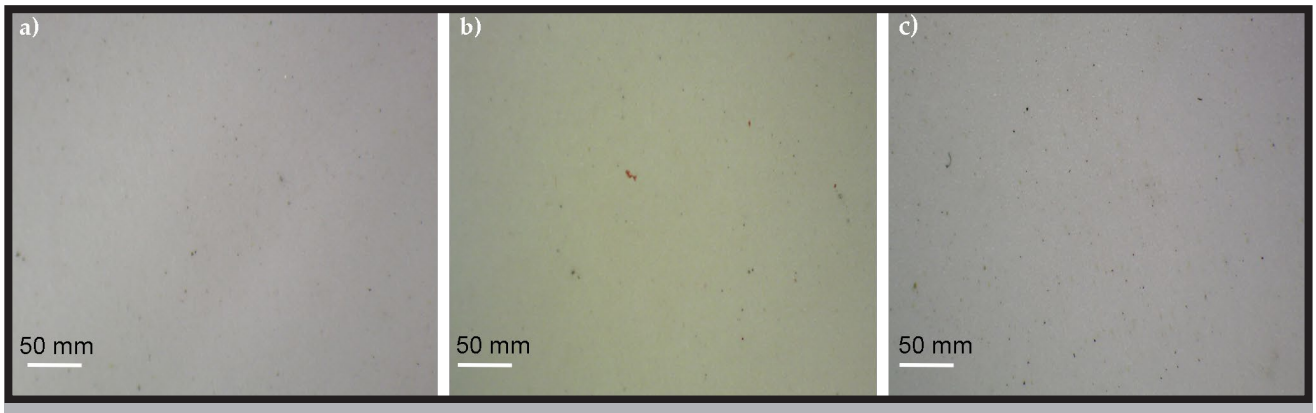

FIG. 1. Microscopic images of polymeric films: a) PVA, b) PVA/Cur, c) PVA/Chi/Cur.

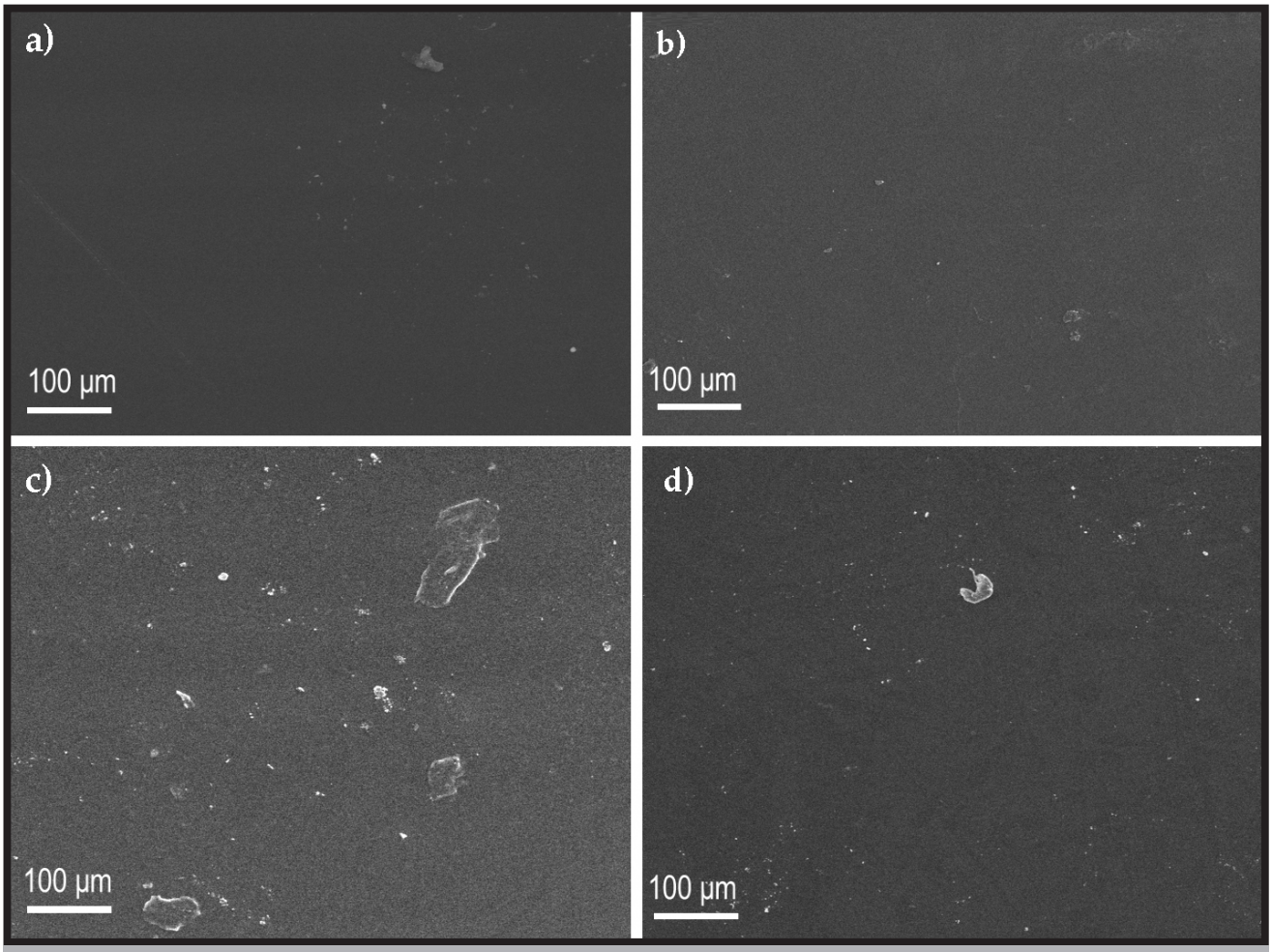

FIG. 2. SEM images: a) Chi, b) PVA, c) PVA/Cur, d) PVA/Chi/Cur.

SEM images are presented in FIG. 2 to view the morphology of the polymeric films of individual polymers and their polymeric blends. FIG. 2a presents SEM image of chitosan (Chi), which can be seen as a flat and smooth surface; a similar analysis has been reported in the literature [47,48]. FIG. 2b shows SEM image of the polyvinyl alcohol (PVA) films, and it demonstrates the uniformity of the surface. It also shows the presence of few flakes, which can be caused due to the semicrystalline nature of poly(vinyl alcohol). The uniformity of the PVA surface has been described by Mahesh et al. [49]. FIG. 2c presents the SEM image of PVA/Cur, showing the presence of curcumin throughout the surface in the form of agglomerates. FIG. 2d shows SEM image of the polymeric blend (PVA/Chi/Cur), and it displays a smooth and uniform surface with agglomerates due to the presence of curcumin. The smooth and uniform surface of PVA/Chi has been described by Costa-Júnior et al. [50].

Fourier Transform Infrared (FTIR) spectroscopy results are depicted in FIG. 3. It presents a comparative stack analysis of all recorded spectra. The FTIR spectrum of chitosan (Chi) shows an intense band at 3265 cm^{-1} resulting from the overlap of the O-H and N-H bonds as mentioned by Kulig et al. [51]. The higher peak at 2921 cm^{-1} and the lower-intensity peak at 2872 cm^{-1} are due to the C-H stretching [52]. The peak at 1633 cm^{-1} is caused due to the -CONHR group and the peak at 1540 cm^{-1} is due to the amine group [53]. The reason for the peaks that appeared at 1404 cm^{-1}, and 1377 cm^{-1} is the CH_3 symmetrical deformation. The intense peak at 1023 cm^{-1} describes the C-O stretching [54].

The main peaks observed in the FTIR spectrum of polyvinyl alcohol (PVA) are related to hydroxyl and acetate groups because polyvinyl alcohol is prepared by hydrolysis of poly(vinyl acetate). The largest peak was observed at 3259 cm^{-1} (*v* O-H*).* The peak observed with the O-H functional group is due to intermolecular and intramolecular hydrogen bonding. The peaks observed at 2905 cm^{-1} (*v* C-H alkyl group) [55,56], the peaks noticed at 1651 cm^{-1}, and 1141 cm^{-1} are due to the stretches of the carboxyl group [57]. The strong peak is presented at 1563 cm^{-1}. Deshkulkarni et al. have mentioned that this peak is due to the benzenoid ring [58]. The sharp band appeared at 1084 cm^{-1} and is due to the C-O stretching of the C-O-H group. Stretching vibrations have been observed at 916 cm^{-1} and 832 cm^{-1} due to the C-H group [59].

FTIR spectra of curcumin (Cur) have demonstrated the characteristic bands at 2944, 2846 and 1428 cm^{-1}. These characteristic bands are due to the C-H stretching and because of the deformation of the methyl groups - similar results were presented in the literature by Abadeh [60]. Curcumin (Cur) has also shown a medium intensity peak at 3510 cm^{-1} (*v* O-H phenol), 1628 cm^{-1} (*v* C=O ketonic), and 1277 cm^{-1} (*v* C-O phenol). Strong intensity peaks have been shown at 1602 cm^{-1} (*v* C=O ketonic) and 1509 cm^{-1} (*v* C=C aliphatic) [61].

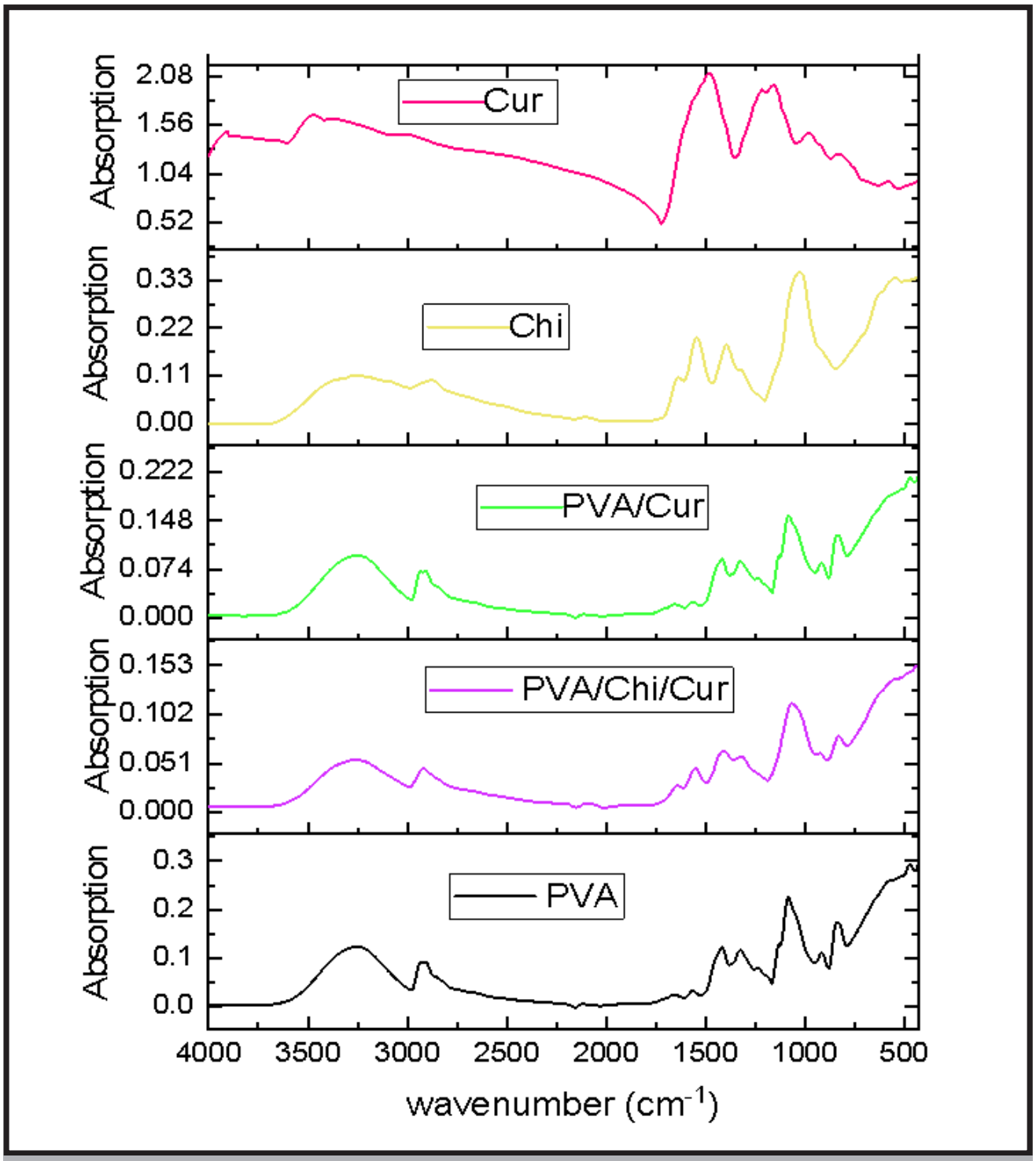

FIG. 3. Comparative stack spectrum of polymeric films and curcumin powder.

The FTIR spectrum of PVA/Cur was analyzed, and it presented the absorption band at 3260 cm^{-1}, resulting from the OH groups and intermolecular hydrogen bonding between them. A band at 1560 cm^{-1} is caused by the carboxylate group, or due to the inter-molecularly bonded water. The peak at 1416 cm^{-1} comes from the polyvinyl alcoholic groups. The peak at 1375 cm^{-1} is resulted due to the addition of curcumin (Cur). The addition of curcumin to the polymeric solution of polyvinyl alcohol modified the FTIR peaks.

The FTIR spectrum of the polymeric blend of PVA/Chi/Cur presents the absorption band at 3254 cm^{-1} and it is caused by the intermolecular hydrogen bonding with the presence of O-H functional group. The peak at 2938 cm^{-1} is due to the presence of the alkyl group. A band that appeared at 1555 cm^{-1} is due to the amine group of chitosan. The peak at 1378 cm^{-1} is due to the presence of curcumin in the polymeric blend. The addition of chitosan modified the position of the peaks of the polymeric blend of the PVA/Cur which suggests the interactions between polymers via hydrogen bonds. FTIR spectra have also confirmed morphological studies of the polymeric films in the form of the functional groups presence.

The results of the mechanical properties of the polymeric films are presented in TABLE 1. The results in the table are indicated as the average value with the standard deviation value. The highest value of Young's modulus was observed in the case of chitosan films (Chi), and the lowest Young's modulus was obtained in the case of poly(vinyl alcohol) films (PVA). The tensile strength was the highest for chitosan (Chi), and the tensile strength was the lowest for the polymeric blend (PVA/Chi/Cur). The highest value of breaking force or stress was recorded for PVA, and it was the lowest in the polymeric blend (PVA/Chi/Cur). Elongation percentage presented the highest value for polyvinyl alcohol (PVA), whereas the lowest value was found for the chitosan film (Chi).

The results of mechanical properties are presented in the form of bar graphs in FIGs. 4, 5, 6, and 7. The bar graphs show the mechanical properties average value with the error bars. Error values have been calculated following the standard deviation values, and the standard deviation has been calculated following the variance. These values were obtained with the help of the ANOVA test. The mechanical properties of the blend prepared in this research are sufficient for applications as wound dressing.

TABLE 1. Mechanical properties of polymers.

Sr. No.	Polymers	Young's Modulus [GPa]	Tensile Strength [MPa]	Stress [N]	Elongation [%]
1	PVA	0.99 ± 0.22	49.04 ± 1.30	13.20 ± 2.65	180.09 ± 27.09
2	Chi	3.11 ± 0.69	69.43 ± 3.69	10.77 ± 1.76	7.83 ± 1.23
3	PVA/Cur	1.00 ± 0.24	50.39 ± 1.63	13.09 ± 2.37	145.91 ± 22.67
4	PVA/Chi/Cur	1.49 ± 0.36	47.69 ± 3.85	8.39 ± 4.29	35.34 ± 19.28

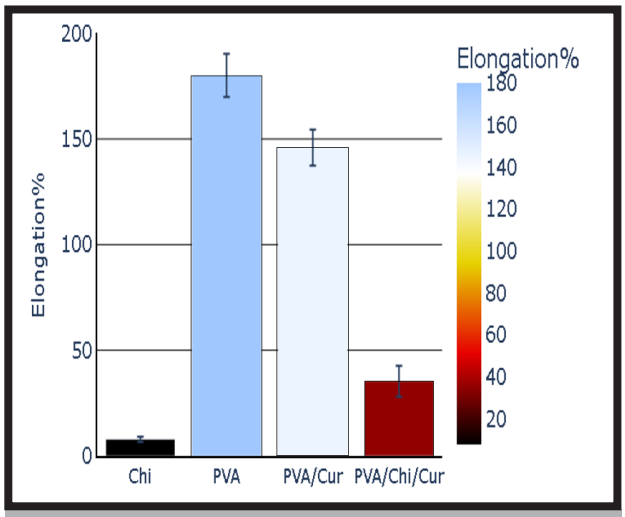

FIG. 4. Elongation at break of polymer films.

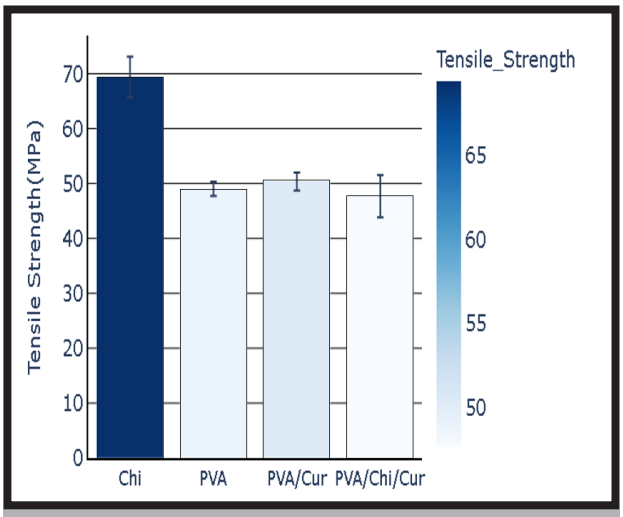

FIG. 6. Tensile strength of polymer films.

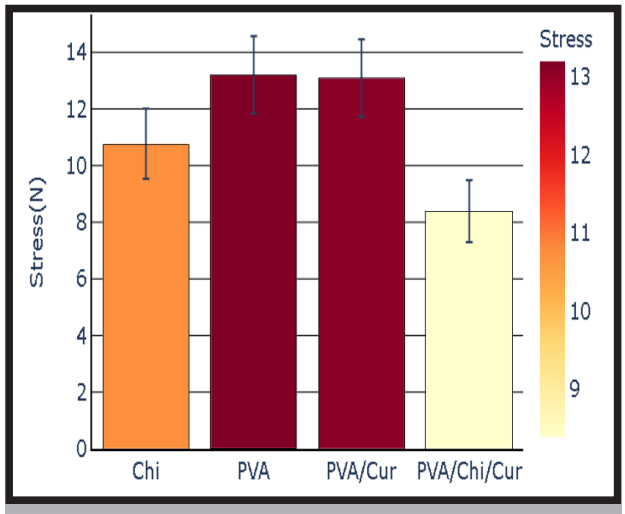

FIG. 5. Stress of polymer films.

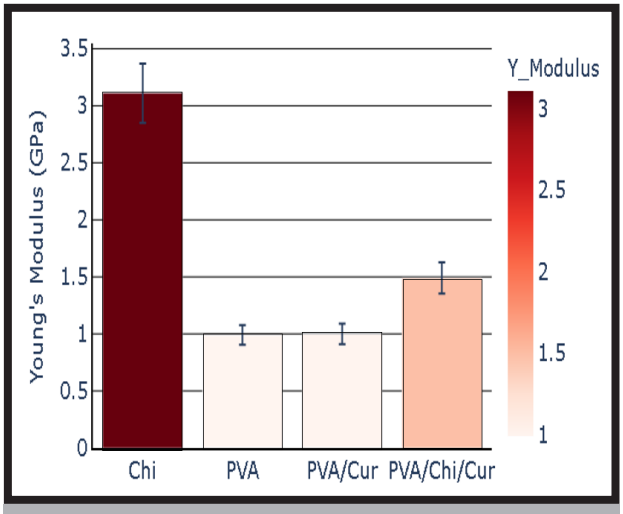

FIG. 7. Young's Modulus of polymer films.

Conclusions

A polymer composite based on the blend of PVA and chitosan with curcumin has been successfully obtained. The presence of components in the composite was confirmed by FTIR spectroscopy. The mechanical properties of the composite were different than those of the single components. The elasticity and elongation percentage of the chitosan film was observed with a rather small value. The PVA polymeric blend containing chitosan showed decreased ductility and elongation percentage. The elasticity of the polymeric blend containing polyvinyl alcohol, curcumin, and chitosan was found to be higher than those for the chitosan film. The composite obtained in this study may help to maintain a moist environment for the wound and increase the protection against microbial attack and to prevent the wound from open exposure to oxygen.

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