A comparison of silver nanoparticles made by green chemistry and femtosecond laser ablation and injected into a PVP/PVA/chitosan polymer blend

A. L. Waly¹,*, A. M. Abdelghany²,³, and A. E. Tarabiah⁴

¹ Basic Science Department, Higher Institute of Engineering and Technology, New Damietta, Egypt
² Spectroscopy Department, Physics Research Institute, National Research Center, 33 ElBehouth St., Dokki, Cairo 12311, Egypt
³ Basic Science Department, Horus University, International Coastal Road, New Damietta, Kafr Saad, Damietta, Egypt
⁴ Dental Biomaterials Department, Faculty of Oral and Dental Medicine, Delta University for Science and Technology, Gamassa, Egypt

Received: 7 June 2022
Accepted: 5 September 2022
Published online: 19 September 2022
© The Author(s), under exclusive licence to Springer Science+Business Media, LLC, part of Springer Nature 2022

ABSTRACT

Due to their antibacterial effect, silver nanoparticles (AgNPs) are attracting more and more attention for various applications in biomedicine. The production of nanomaterials from organometallic precursors requires the use of a capping agent that acts as a stabilizer and provides colloidal stability while preventing agglomeration and excessive growth. In this research, we studied the optical properties and antibacterial activity of AgNPs loaded in a blend of polyvinylpyrrolidone (PVP), polyvinyl alcohol (PVA), and chitosan, which were used as capping agents to control the shape and size of the nanoparticles and to impart stability to the synthesized Ag nanomaterials. Characterization studies showed that the blend provides a uniform and controlled distribution of AgNPs inside the polymeric matrix without the addition of any more stabilizers. The mean particle size for green and laser-ablated AgNPs was found to be ~50 nm according to transmission electron microscopy (TEM) studies. Fourier transform infrared (FTIR) studies showed the presence of characteristic main peaks corresponding to the vibrational groups which characterize the prepared samples. The interactions between the AgNPs and the blend were marked by changes in the intensity of vibrational peaks and spectral positions. X-ray diffraction (XRD) confirmed the crystallographic modification within the PVP/PVA/chitosan matrix because of AgNPs filling. The change in the absorbance has been studied with the help of measured ultraviolet-visible spectroscopy (UV-Vis.) and therefore the optical band gap was calculated. The filling of AgNPs in the blend shows a broad peak at 427 nm because of the phenomenon of surface plasmon resonance (SPR) and its intensity increases with increasing filler concentration. The blend and the Ag nanocomposite showed remarkable antibacterial activity and caused a significant decrease in microbial growth (Escherichia coli) in 24 h.

Address correspondence to E-mail: Ahmedwaves20@yahoo.com

https://doi.org/10.1007/s10854-022-09082-z
These outcomes demonstrate the suitability and promise of the nanocomposites for various applications, including biomedical labels, sensors, and detectors.

1 Introduction

Silver nanoparticles (AgNPs) are among the most important materials used in research and industrial fields in the current century. One of the most important characteristics of nanometric silver particles is the improvement of many physical and biological properties significantly over bulk silver, which we find in changing the optical, electrical, and also antibacterial properties. AgNPs can be used in a variety of applications, such as antibacterial agents [1], sensors [2], solar cells [3], and electronics [4].

Polymer composites are one of the most interesting near-term means for taking the advantage of the important features of AgNPs. Polyvinyl alcohol (PVA) is a remarkable polymer because of its chemical and physical properties and has therefore drawn researchers’ attention over the years. PVA is a biocompatible, chemically stable compound and has a semi-crystalline nature resulting from the role of the OH groups and hydrogen bonding [5]. It can create a strong interchain and intrachain hydrogen bonding and can also interact with other polymers via chemical bonding or hydrogen bonding between groups. PVA has major applications such as biomedicine, food packaging, and water filtration [6]. It has high dielectric strength, a good charge storage capacity, and optical and electrical properties that depend on the filling [7]. Additionally, PVA is used as a capping agent to control the nanoparticles shape and size and to impart stability to many synthesized nanoparticles such as AgNPs.

Polyvinylpyrrolidone (PVP) is also a water-soluble polymer, a pH stable, non-toxic, biodegradable, and biocompatible polymer that helps encapsulate and deliver lipophilic and hydrophilic drugs [8]. PVP can serve as a nanoparticle dispersant, reducing agent, growth modifier, and surface stabilizer depending on specific synthesis conditions and material system. It was considered to be a potential material with very good film formability for potential applications in the manufacture of plastics, adhesives, protectants, coatings, paints, detergents, printing inks, and cosmetics [9].

Chitosan is a chitin-based natural polymer and has excellent non-toxic, antimicrobial, biocompatible, and biodegradable properties [10–12]. Chitin is found in the cell walls of fungi, arthropod exoskeletons, such as crustaceans and insects, crabs, cephalopods, scales of fish, and Lissamphibia [13]. Filling the chitosan matrix with Ag nanoparticles has immense potential in medicine, especially in wound dressings, where the chitosan matrix would help to control the release of Ag nanoparticles, thereby reducing the Ag toxicity to normal cells [14].

PVA, PVP, and chitosan are used as capping agents to regulate the nanoparticle shape and size and to impart stability to the synthesized Ag nanomaterials. Also, PVA and PVP are used as reducing agents which provide free electrons to reduce Ag ions and form Ag nanoparticles [15].

Several studies report the addition of chemically and green-synthesized silver nanoparticles to polymeric matrices, especially for medical and food packaging applications [16–19].

The present study aims to synthesize a novel composite membrane from a PVP/PVA/chitosan blend filled with different concentrations of silver nanoparticles (green synthesized and laser ablated), with a simple method for the production and investigation of their physical properties. An in-depth study of the optical and structural properties of this system is discussed using various techniques and tools.

2 Experimental work

2.1 Materials

PVA (provided by S.D. Fine-Chem India—14,000 MW), PVP (provided by SISCO Research Laboratory India—40,000 MW), and chitosan (from Fluka, USA) were utilized as a blended matrix for filling with AgNPs (synthesized by green chemistry and femtosecond laser ablation method); the distilled water was used as a solvent.
2.2 Samples preparation

Silver nanoparticles were prepared as previously described in previous work [20–23]. Separately, PVA and PVP were dissolved in distilled water and agitated at 65 °C for about 5 h, while chitosan was prepared by dissolving in distilled water containing 2% acetic acid. They are mixed to form a blend from 40% by weight of PVA, 40% by weight of PVP, and 20% by weight of chitosan.

The AgNPs in distilled water was combined with the polymer blend in precalculated amounts under the same conditions to obtain samples of nanocomposite with different concentrations of AgNPs as shown in Table 1, where the highest content of AgNPs filling (H-green and H-laser ablated) is 5% and the lowest content of AgNPs filling (L-green and L-laser ablated) is 1%. After that, the solution was placed into Petri plates at 45 °C for approximately 48 h. After complete drying, the nanocomposite films were peeled off from the Petri dishes and preserved in desiccators under a vacuum until their use.

2.3 Physical characterization

The Fourier transform infrared spectroscopy (FTIR) data were collected within the spectral region 4000–400 cm\(^{-1}\) at room temperature using a Nicolet iS10 FTIR single-beam spectrometer. PANalytical X’Pert PRO XRD was used to record X-ray diffraction (XRD) scans of the prepared samples using Cu-K\(\alpha\) radiation with a wavelength of 1.54 Å using a current of 40 mA, and a voltage of 45 kV. The measurements were done for Bragg’s angle (2\(\theta\)) in the range of 5°–70°. A transmission electron microscope was used to scan the size and shape of the nanoparticles (JEOL-JEM-1011, Japan). Electronic spectra in the wavelength range of 200 to 1100 nm were measured via (JASO V570) double-beam spectrophotometer using air as the reference.

3 Results and discussion

3.1 Fourier transform infrared (FTIR)

FTIR spectra of chitosan, PVP, PVA, unfilled, and filled PVP/PVA/chitosan blends with different AgNP contents are shown in Fig. 1a and b. The spectra revealed the characteristic peaks of bending and stretching vibrations for the functional groups found in the prepared films. Table 2 shows the peak positions of the FTIR absorption bands and their assignments for the produced films.

In the case of pure PVA (Fig. 1a), the broadness and absorbance at about 3265 cm\(^{-1}\) are attributed to the stretching vibration of the hydroxyl groups (OH) of PVA [24, 25]. The asymmetric CH\(_2\) stretching vibration is responsible for the peak at 2938 cm\(^{-1}\). The bands at 1710 and 1661 cm\(^{-1}\) were assigned to the C=O and C=C stretching modes [25, 26]. The absorption peak at 1420 cm\(^{-1}\) was attributed to the CH\(_2\) symmetrical bending, while the peak at 1327 cm\(^{-1}\) is assigned to (CH\(_2\)?OH) bending [27]. The C–O stretch of the carbonyl groups in the PVA backbone corresponds to the band at about 1088 cm\(^{-1}\). The OH wagging is responsible for the peak at 593 cm\(^{-1}\), whereas the CH\(_2\) rocking is responsible for the peak at 917 cm\(^{-1}\) [26]. The peaks at 1140 cm\(^{-1}\) and 842 cm\(^{-1}\) have been assigned to C–C stretching vibrations with moderate absorption that corresponds to the crystalline regions in PVA [28].

For PVP, the absorbance observed at 3396 cm\(^{-1}\) is attributed to (OH) stretching [29], while the absorbance at 1437 cm\(^{-1}\) and 843 cm\(^{-1}\) correspond, respectively, to the CH\(_2\) scissoring vibrations and

| Table 1 Sample nomination and composition |
|------------------------------------------|
| PVP | PVA | Chitosan | Blend | L-green AgNPs (1%) | H-green AgNPs (5%) | L-laser-ablated AgNPs (1%) | H-laser AgNPs (5%) |
|-----|-----|---------|------|-------------------|------------------|------------------------|-----------------|
| PVP | 100 | 0.0     | 0.0  | 40               | 39.6             | 38                     | 38              |
| PVA | 0.0 | 100     | 0.0  | 40               | 39.6             | 38                     | 38              |
| Chitosan | 0.0 | 0.0  | 100  | 20               | 19.8             | 19                     | 19              |
| AgNPs | 0.0 | 0.0 | 0.0  | 0.0             | 1                | 5                      | 5               |
CH₂ bending, C=O stretching and C–N stretching are given to the peaks at 1644 cm⁻¹ and 1017 cm⁻¹, respectively [30–32].

Chitosan spectra showed a peak at 3290 cm⁻¹ which is attributed to OH stretching, while at 2875 cm⁻¹ is attributed to CH₂ stretching. The vibrational mode of amide C=O stretching was observed at
Table 2 FTIR absorption bands and their assignments for a pure PVA, b pure PVP, c Chitosan, and d unfilled and filled PVP/PVA/chitosan blend with AgNPs

| Band assignment                                      | Wavenumber (cm$^{-1}$) | Ref          |
|------------------------------------------------------|-------------------------|--------------|
|                                                      | PVA        | PVP        | Chitosan | Blend          |
| OH stretching                                        | 3265       | 3396       | 3290     | 3280           | [24, 25, 29, 38] |
| N–H stretching of secondary amide                   | 2974       | 2938       | 2949     | 2933           | [29]          |
| CH2 asymmetric stretching                            | 2908       | 2859       | 2875     | 2875           | [25, 26, 29, 34, 39] |
| CH2 symmetric stretching                             | 1710       | 1644       | 1645     | 1644           | [25, 26, 29, 32, 39] |
| C=O stretching                                       | 1661       | 1493       | 1420     | 1420           | [26, 31, 32, 34, 38–41] |
| N–H bending (amide II band)                          | 1437       | 1416, 1422, 1417, 1372, 843 | 1563 | [29, 39]       |
| Characteristic vibration of C=N (pyridine ring)      | 1420       | 1461, 1422, 1372, 843 | 1416  | 1422           | [26, 31, 32, 34, 38–41] |
| CH2 bending                                          | 1374, 1287 | 1287       | 1287     | 1287           | [25, 26, 31, 38] |
| CH2 scissoring vibrations                            | 1374, 1287 | 1287       | 1287     | 1287           | [25, 26, 31, 38] |
| (CH + OH) bending                                    | 1140, 842  | 1217, 933  | 842      | 415            | [25, 26, 32, 42] |
| Asymmetric bridge oxygen stretching (glycosidic linkage) | 1110       |            |          |                | [39]          |
| C–O stretching                                       | 1088       | 1088       | 1044     | 1044           | [26, 34, 39] |
| C–O bending                                          | 476        | 917        | 733      | 811            | [30, 34]       |
| C–N stretching vibrations                            | 1017       | 593        | 561      | 561            | [26, 32]       |
| CH2 rocking                                          | 917        | 733        |          | 881            | [30, 34]       |
| OH wagging                                           | 593        |            |          |                | [26]          |
| N–H bending                                          | 417        |            |          |                | [26]          |
| CO wagging                                           | 417        |            |          |                | [26]          |
| C–N bending                                          | 645        |            |          |                | [38]          |
| N–C=O bending                                        | 568        | 568        | 568      | 568            | [43]          |

1654 cm$^{-1}$ [33]. C–O–C stretching is assigned to the peak at 1151 cm$^{-1}$, while NH out-of-plane bending is assigned to the peak at 561 cm$^{-1}$ [34]. The most intense band located at about 1654 cm$^{-1}$ is usually attributed to the strong dipole vibration of the carbonyl group in the basic structure of the Chitosan partner.

In the PVP/PVA/chitosan blend sample, most intensities of the absorption peaks differed irregularly from their values in the individual polymers. After blending (and also after filling with AgNPs), a small decrease in the intensity of the CC band peaking at 1140 cm$^{-1}$ and 842 cm$^{-1}$ of the PVA matrix was observed, indicating a decrease in the crystalline phase content [28]. Furthermore, the hydroxyl groups of the blend showed a decrease in intensity and a shift to a lower wavenumber 3280 cm$^{-1}$ because of the hydrogen linking formation between the OH group (of PVA and chitosan) with the C=O of PVP (which also decreased), ensuring the miscibility of the prepared blend [35, 36]. In the spectra of the PVP/PVA/chitosan blend filled with AgNPs, we could not observe any specific bands for AgNPs in the range between 4000 and 400 cm$^{-1}$, since their absorption occurs in far-infrared only, that is, in the range (400–100 cm$^{-1}$) [37]. We, therefore, discuss the AgNPs incorporation in the PVP/PVA/chitosan blend and the interaction between the bonds of the blend and AgNPs.

Figure 1b shows that, for the highest content of AgNPs filling (H-green and H-laser ablated), the peak at 2859 cm$^{-1}$ reappeared which is one of the characteristic peaks of chitosan (CH2 symmetric stretching). There is also new small broadband at 3746 cm$^{-1}$ and a small sharp peak at 414 cm$^{-1}$ with increased AgNPs content. There is also a marked...
change in intensity with a small shift in most peaks in the major characteristic bands of the PVP/PVA/chitosan blend compared to that filled with various contents of AgNPs, which means interaction and complexation between the AgNPs and the PVP/PVA/chitosan blend due to the good miscibility of AgNPs and the blend in present films.

3.2 X-ray diffraction (XRD)

Figure 2a shows the XRD for pure chitosan, PVP, PVA, and the blend, while Fig. 2b reveals the XRD of blend films filled with different concentrations of AgNPs in the extended 2θ range between 5° and 70°. The XRD of the pure PVA reveals diffraction peaks at 2θ = 19.4° and 40.4° due to the partially crystalline nature of the PVA structure supported by intermolecular and intramolecular hydrogen bonds [32]. PVA exhibits as well a low-intensity diffraction peak at 2θ = 22.7° [44]. The chitosan film has a broad diffraction peak at 2θ ≈ 23°, while PVP has very broad diffraction peaks at 2θ = 11° and 22°, confirming the amorphous nature of the chitosan and PVP films examined [10, 32].

For the unfilled PVP/PVA/chitosan blend, it can be seen that the intensity of the peak at 2θ = 19.4° has reduced and become broader. This means that adding PVP and chitosan to PVA reduces the semi-crystalline nature of PVA and indicates high compatibility between the components of the blend.

Filling the blend with AgNPs also reduces the peak intensity at 2θ = 19.4°, which is based on the interaction between the filler and the blend, resulting in less intermolecular interaction between the blend chains and a decrease in the degree of crystallization [29]. This amorphous nature is responsible for the higher ionic diffusion resulting in higher ionic conductivity [45]. This behavior indicates that the PVA/PVP/chitosan blend matrix has been structurally modified as a result of the AgNPs filling and confirms the results obtained in the FTIR studies (Sect. 3.1).

Moreover, it can be seen from the same figure that a highly filled sample (H-ablation) shows a presence of a small peak at about ~ 38°, which may result from precipitated silver within the polymeric matrix corresponding to the Face-Centered Cubic (FCC) structure which corresponds to the (111) plane previously reported [46].

3.3 Transmission electron microscopy (TEM)

To ensure the size and morphology of the produced AgNPs, transmission electron microscopy (TEM) was used. Figure 3 displays the transmission electron microscopic images for the purely green and laser-ablated AgNPs in an aqueous solution, revealing that the nanoparticles are roughly rectangular, randomly distributed, and have diameters ranging from 40 to 110 nm for green and from 20 to 160 nm for laser ablated. Nearly the same size and morphology were obtained after blending with an organic partner.
3.4 UV/Vis absorption and optical studies

Figure 4 displays the UV/visible absorption spectra of the pure PVA, pure chitosan, PVP/PVA/chitosan blend, and unfilled and filled PVP/PVA/chitosan blend with Ag nanoparticles samples.

The spectrum of pure chitosan shows an absorption band at 208 nm, which can be assigned to the chromatic functional groups (NHCOR) and/or the presence of chromophore groups (C=C) or (C=O) [47], while pure PVA shows an absorbance peak at ~ 200 nm that is attributed to an n → π* transition. The PVA transition is associated with the carbonyl groups (C=O) related to ethylene unsaturation (C=C) of the (CH=CH)CO– type. The presence of
carbonyl functionalities might be because of residual acetate groups remaining after the PVA fabrication with the aid of using hydrolysis of polyvinyl acetate or oxidation throughout fabrication and processing [48].

After adding AgNPs (Fig. 5), the nanocomposite samples give a significant increase in the absorbance values at 200 nm with a gradual red shift to longer wavelengths as the AgNPs content increase. This can be assigned to the interaction between polymeric matrices and the added AgNPs affecting the calculated optical bandgap [49] associated with the crystallinity change in the nanocomposite, as discussed earlier in Sect. 3.2. In addition, a peak begins to appear at $\lambda_{\text{max}} = 427$ nm and its intensity continuously increases with the increase of AgNPs concentration. The appearance of this peak in the visible range is caused by the surface plasmon resonance (SPR) nature of the AgNPs inserted in a dielectric medium, which results from the collective excitation of the conduction band electrons in the nanoparticle [49, 50]. The presence of these peaks also indicates that the fabricated blend can be used as a good cabling agent for the AgNPs.

The optical energy gap ($E_g$) can be estimated using the Tauc method [52], which analyzes the spectral dependence of the absorption coefficient $\alpha$ near the absorption edge.

$$\alpha = \frac{B(h\nu - E_g)^r}{h\nu},$$

where $B$ is a constant associated with the electronic transition probability, $h\nu$ is the energy of the incident photons, and the power $r$ is related to the transition behavior and equal to 2 or $\frac{1}{2}$ for the allowed direct and indirect transition, respectively.

$\alpha$ can be calculated from the absorbance $A$ and film thickness ($d$) using $\alpha = \frac{2.303A}{d}$.

Figure 6a and 6b shows a plot of $(a\nu)^2$ and $(a\nu)^{1/2}$ with $h\nu$ for the prepared samples. Extrapolating the linear fit lines in these data points on the $h\nu$ axis yields the optical band gap values, which are listed in Table 3.

The calculated optical bandgaps decrease with increasing AgNPs content and are assigned to the role of AgNPs in modulating the structure caused by the formation of variable polaronic and defect levels that are related to localized states density $N(E)$ [53].

At lower energies below the fundamental absorption edge, spectral data revealed the appearance of an elongated tail that correlates with the localized states in the valence band tail, attributed to defects formed by AgNPs, and extends to states in the conduction band. In such a case, the absorption coefficient $\alpha$ can be entirely attributed to the energy tail width $\Delta E$ and the photon energy which is thermal vibration in the lattice [20] and can be determined by the Urbach formula [54].

$$\alpha = \alpha_0 \exp \left( \frac{h\nu}{\Delta E} \right),$$

where $\alpha_0$ is a constant.

Urbach energy ($\Delta E$) values can be estimated from the slope of the logarithm of absorption coefficient ($\alpha$) against photon energy ($h\nu$) as plot shown in Fig. 7. Calculated values of Urbach energy ($\Delta E$) are listed in Table 3. For the pure blend, the value of $\Delta E$ is 0.16 eV and that of the filled samples is increased up to 0.23 eV.

The increase in Urbach energy confirms the increase in the width of localized states within the bandgap and hence is responsible for bandgap decay of the filled samples.

3.5 Antibacterial studies

Antibacterial characteristics of the studied samples containing both high- and low-level dopants of both
green-synthesized and silver-ablated nanoparticles were performed against two gram-positive and two gram-negative bacteria, namely \(E.\) \(Coli,\) \(Pseudomonas\) \(aeruginosa,\) \(S.\) \(aureus,\) and \(B.\) \(Cereus.\) The minimum inhibition zone (MIZ) agar diffusion method was used. Polymeric samples with nearly equal diameters were seeded in the bacterial medium and incubated at 37 \(\degree\)C for 24 h. Sample concentrations and their corresponding inhibition zone in (mm) are listed in Table 4.

Obtained data show the effect of adding silver nanoparticles to the polymeric matrix. It was noticed that the inhibition zone in the case of samples containing silver nanoparticles is generally increasing and the result appears promising and with higher value, in the case of ablated laser, this may be attributed to both the size and monodisperse distribution of the nanoparticle. It was also clear that the effect of all samples against gram-positive bacteria is slightly increasing than that of gram-negative bacteria as shown in Fig. 8. Such behavior can be considered in terms of the rapid generation of free radicals through redox reaction, while reactive oxygen species ROS can react directly with membrane components including proteins, lipids, and DNA that are scavenged by antioxidants resulting in oxidative stress in bacterial cells [55].

4 Conclusion

PVP/PVA/chitosan samples injected with two types of synthesized silver nanoparticles were prepared via a common solution casting technique. X-ray analysis showed that after filling with highly ablated AgNPs, a peak at 38 is generated, which can be attributed to the face-centered cubic structure (fcc) of the embedded silver nanoparticles, which corresponds to \(h\) \(k\) \(l\) parameters (111). The interaction and complexation with the prepared polymers and/or AgNPs were

| Sample       | \(E_{\text{gid}}\) (eV) | \(E_{\text{gd}}\) (eV) | \(\Delta E\) (eV) |
|--------------|------------------------|-----------------------|------------------|
| Blend        | 4.94                   | 5.25                  | 0.16             |
| L Ag green   | 4.93                   | 5.24                  | 0.16             |
| L Ag ablated | 4.91                   | 5.21                  | 0.17             |
| H Ag green   | 4.87                   | 5.20                  | 0.18             |
| H Ag ablated | 4.85                   | 5.19                  | 0.23             |

Fig. 6 The plots of a) \((\chi h)^{1/2}\) and b) \((\chi h)^2\) versus \((h)v\) for the blend filled with different contents of AgNPs

Fig. 7 Logarithm of absorption coefficient \(\alpha\) versus photon energy \((h)v\) for the blend filled with different contents of AgNPs
revealed by UV/visible and FTIR spectroscopic data. This interaction and complexation can be seen in the growth and red shift of the UV band, which can be attributed to the intermolecular interaction between hydrogen bonds. It has been shown that the optical band gaps are considerably reduced by the filling, where the filling with silver nanoparticles forms the levels of traps rich in charge carriers. All of these data support the idea of complexation between AgNPs and the blend matrix. TEM images confirmed the existence of silver nanoparticles with a mean diameter of ~50 nm. The blend and the Ag nanocomposite showed good antibacterial activity and caused a significant decrease in microbial growth (Escherichia coli) in 24 h. Both optical and antibacterial properties of studied samples show a clear disparity between samples injected by green-synthesized and laser-ablated silver nanoparticles.

### Author contributions

Writing and preparation of the original draft and investigation were done by ALW; conceptualization, methodology validation, formal analysis, writing, reviewing, and editing of the manuscript, supervision, project administration, and funding acquisition were done by AMA; writing, reviewing, and editing of the manuscript, supervision, and project administration were done by AET; writing, reviewing, and editing of the manuscript, supervision, and project administration were done by B.B.; writing, reviewing, and editing of the manuscript, supervision, and project administration were done by F.N.

---

| Sample  | *E. coli* | *Pseudomonas aeruginosa* | *S. aureus* | *B. cereus* |
|---------|-----------|-------------------------|-------------|------------|
| Blend   | 12        | 12                      | 11          | 11         |
| Green L | 13        | 14                      | 13          | 12         |
| Green H | 14        | 15                      | 15          | 14         |
| Laser L | 15        | 17                      | 17          | 16         |
| Laser H | 15        | 17                      | 18          | 17         |

**Table 4** Sample concentrations and their corresponding inhibition zone in (mm)

---

**Fig. 8** Correlation between sample concentrations and their corresponding inhibition zone in (mm)
administration were done by ALW; all the authors have read the manuscript and have approved this submission.

**Funding**

The authors have not disclosed any funding.

**Data availability**

The data presented in this study are available within this article.

**Declarations**

**Conflict of interest** There is no conflict to declare.

**References**

1. T. Bruna, F. Maldonado-Bravo, P. Jara, N. Caro, Silver nanoparticles and their antibacterial applications. Int. J. Mol. Sci. 22, 7202 (2021)
2. M. Alauhdin, M. Avissa, I.P. Islami, S.K. Rahmawati, Silver nanoparticle-based colorimetric sensors for metal ions detection: a narrative review, advanced sustainable. Engineering 1, 17–23 (2021)
3. S. Sreeja, S. Prabhakaran, B. Pesala, Efficiency enhancement of betanin dye-sensitized solar cells using plasmon-enhanced silver nanoparticles, advances in energy research. Springer 1, 9–18 (2020)
4. L. Mo, Z. Guo, L. Yang, Q. Zhang, Y. Fang, Z. Xin, Z. Chen, K. Hu, L. Han, L. Li, Silver nanoparticles based ink with moderate sintering in flexible and printed electronics. Int. J. Mol. Sci. 20, 2124 (2019)
5. A.L. Waly, A.M. Abdelghany, A.E. Tarabiah, Study the structure of selenium modified polyethylene oxide/polyvinyl alcohol (PEO/PVA) polymer blend. J. Market Res. 14, 2962–2969 (2021)
6. M.I. Baker, S.P. Walsh, Z. Schwartz, B.D. Boyan, A review of polyvinyl alcohol and its uses in cartilage and orthopedic applications. J. Biomed. Mater. Res. Part B 100, 1451–1457 (2012)
7. E.M. Abdelrazek, A.M. Abdelghany, A.E. Tarabiah, H.M. Zidan, AC conductivity and dielectric characteristics of PVA/PVP nanocomposite filled with MWCNTs. J. Mater. Sci. 30, 15521–15533 (2019)
8. M. Kurakula, G.S.N.K. Rao, Pharmaceutical assessment of polyvinylpyrrolidone (PVP): as excipient from conventional to controlled delivery systems with a spotlight on COVID-19 inhibition. J. Drug Deliv. Sci. Technol. 60, 102046 (2020)
9. M. Voronova, N. Rubleva, N. Kochkina, A. Afineevskii, A. Zakharov, O. Surov, Preparation and characterization of polyvinylpyrrolidone/cellulose nanocrystals composites. Nanomaterials 8, 1011 (2018)
10. F. Gami, N. Algethami, H.M. Ragab, A. Rajah, A.E. Tarabiah, Structural, optical and electrical studies of chitosan/polyacrylamide blend filled with synthesized selenium nanoparticles. J. Mol. Struct. 1257, 132631 (2022)
11. A. Rebekah, S. Sivaselvam, C. Viswanathan, D. Prabhhu, R. Gautam, N. Ponpandian, Magnetic nanoparticle-decorated graphene oxide-chitosan composite as an efficient nanocarrier for protein delivery. Coll. Surf., A 610, 125913 (2021)
12. A. Rebekah, G. Bharath, M. Naushad, C. Viswanathan, N. Ponpandian, Magnetic graphene/chitosan nanocomposite: a promising nano-adsorbent for the removal of 2-naphthol from aqueous solution and their kinetic studies. Int. J. Biol. Macromol. 159, 530–538 (2020)
13. N. Morin-Crini, E. Lichtfouse, G. Torri, G. Crini, Applications of chitosan in food, pharmaceuticals, medicine, cosmetics, agriculture, textiles, pulp and paper, biotechnology, and environmental chemistry. Environ. Chem. Lett. 17, 1667–1692 (2019)
14. A. Mohandas, S. Deepthi, R. Biswas, R. Jayakumar, Chitosan based metallic nanocomposite scaffolds as antimicrobial wound dressings. Bioact. Mater. 3, 267–277 (2018)
15. K. Varner, J. Sanford, A. El-Badawy, D. Feldhake, R. Venkatapathy, State of the science literature review: everything nanosilver and more, vol. 363 (US Environmental Protection Agency, Washington DC, 2010)
16. S.P. Deshmukh, S.M. Patil, S.B. Mullani, S.D. Delekar, Silver nanoparticles as an effective disinfectant: a review. Mater. Sci. Eng., C 97, 954–965 (2019)
17. S. Kumar, I.B. Basumatary, H.P.K. Sudhani, V.K. Bajpai, L. Chen, S. Shukla, A. Mukherjee, Plant extract mediated silver nanoparticles and their applications as antimicrobials and in sustainable food packaging: a state-of-the-art review. Trends Food Sci. Technol. 112, 651–666 (2021)
18. J.O. Echavarria, N.A.G. Vanegas, C.P.O. Orozco, Chitosan/carboxymethyl cellulose wound dressings supplemented with biologically synthesized silver nanoparticles from the ligninolytic fungus Anamorphous Bjerkandera sp. R1. Heliyon 8(9), e10258 (2022)
19. I.R.S. Vieira, A.P.A.D. de Carvalho, C.A. Conte-Junior, Recent advances in biobased and biodegradable polymer nanocomposites, nanoparticles, and natural antioxidants for antibacterial and antioxidant food packaging applications. Comp. Rev. Food Sci. Food Safe. 21, 3673–3716 (2022)
20. A.M. Abdelghany, A.A. Menazea, M.A. Abd-El-Maksoud, T.K. Khatab, Pulsed laser ablated zeolite nanoparticles: a novel nano-catalyst for the synthesis of 1, 8-dioxo-octahydroxanthen and N-aryl-1, 8-dioxecelehydroacridine with molecular docking validation. Appl. Organomet. Chem. 34, e5250 (2020)

21. A.A. Al-Shamari, A.M. Abdelghany, H. Alnattar, A.H. Oraby, Structural and optical properties of PEO/CMC polymer blend modified with gold nanoparticles synthesized by laser ablation in water. J. Market Res. 12, 1597–1605 (2021)

22. F.R. El Awady, M.A. Abbas, A.M. Abdelghany, Y.A. El-Amier, Silver modified hydrophytes for heavy metal removal from different water resources. Biointerface Res. Appl. Chem. 11, 14555–14563 (2021)

23. A.M. Abdelghany, A.H. Oraby, M.O. Farea, Influence of green synthesized gold nanoparticles on the structural, optical, electrical and dielectric properties of (PVP/SA) blend. Physica B 560, 162–173 (2019)

24. S. Luo, X. Qiao, Q. Wang, Y. Zhang, P. Fu, Z. Lin, F. Du, C. Cheng, Excellent self-healing and antifogging coatings based on polyvinyl alcohol/hydrolyzed poly(styrene-co-maleic anhydride). J. Mater. Sci. 54, 5961–5967 (2019)

25. G.M. Kim, A.S. Asran, G.H. Michler, P. Simon, J.S. Kim, Electrospun PVA/HAp nanocomposite nanofibers: biomimetics of mineralized hard tissues at a lower level of complexity. Bioinspir. Biomim. 3, 046003 (2008)

26. I. Omkaram, R.P.S. Chakradhar, J.L. Rao, EPR, optical, infrared and raman studies of VO2+ ions in polyvinylalcohol films. Physica B 388, 318–325 (2007)

27. D.M. Ayaad, M.Y.A. Abdelaal, A.M. Abeelkeir, A.M. Abdelghany, Performance enhancement of chitosan filled silver vanadate nano-rods. J. Inorg. Organomet. Polym. Mater. 29, 901–907 (2019)

28. A.N. Krklješ, M.T. Marinović-Cincović, Z.M. Kacarević-Popović, J.M. Nedeljković, Radiolytic synthesis and characterization of Ag-PVA nanocomposites. Eur. Polymer J. 43, 2171–2176 (2007)

29. E.M. Abdelrazek, I.S. Elashmawi, S. Labeeb, Chitosan filler effects on the experimental characterization, spectroscopic investigation and thermal studies of PVA/PVP blend films. Physica B 405, 2021–2027 (2010)

30. M. Kumar, P. Devi, A. Kumar, Structural analysis of PVP capped silver nanoparticles synthesized at room temperature for optical, electrical and gas sensing properties. J. Mater. Sci. 28, 5014–5020 (2017)

31. A.M. Abdelghany, E.M. Abdelrazek, S.I. Badr, M.A. Morsi, Effect of gamma-irradiation on (PEO/PVP)/Au nanocomposite: materials for electrochemical and optical applications. Mater. Des. 97, 532–543 (2016)

32. H.M. Zidan, E.M. Abdelrazek, A.M. Abdelghany, A.E. Tarabiah, Characterization and some physical studies of PVA/PVP filled with MWCNTs. J. Market Res. 8, 904–913 (2019)

33. N. Algethami, A. Rajeh, H.M. Ragab, A.E. Tarabiah, F. Gami, Characterization, optical, and electrical properties of chitosan/polyacrylamide blend doped silver nanoparticles. J. Mater. Sci. (2022). https://doi.org/10.1007/s10854-022-0485-5

34. R. Varma, S. Vasudevan, Extraction, characterization, and antimicrobial activity of chitosan from horse mussel modiolus modiolus, ACS. Omega 5, 20224–20230 (2020)

35. D. Mondal, M.M.R. Mollick, B. Bhowmick, D. Maity, M.K. Bain, D. Rana, A. Mukhopadhyay, K. Dana, D. Chattopadhyay, Effect of poly (vinyl pyrrolidone) on the morphology and physical properties of poly (vinyl alcohol)/sodium montmorillonite nanocomposite films. Prog. Nat. Sci. 23, 579–587 (2013)

36. E. Karavas, E. Georgarakis, D. Bikiaris, Adjusting drug release by using miscible polymer blends as effective drug carriers. J. Therm. Anal. Calorim. 84, 125–133 (2006)

37. A. Fielicke, I. Rabin, G. Meijer, Far-Infrared spectroscopy of small neutral silver clusters. J. Phys. Chem. A 110, 8060–8063 (2006)

38. E.M. Abdelrazek, A.M. Abdelghany, S.I. Badr, M.A. Morsi, Structural, optical, morphological and thermal properties of PEO/PVP blend containing different concentrations of biosynthesized Au nanoparticles. J. Market Res. 7, 419–431 (2018)

39. T.K. Varun, S. Senani, N. Jayapal, J. Chikkerur, S. Roy, V.B. Tekulapally, M. Gautam, N. Kumar, Extraction of chitosan and its oligomers from shrimp shell waste, their characterization and antimicrobial effect. Vet. world 10, 170 (2017)

40. V. Sharma, D. Verma, G.S. Okram, Influence of surfactant, particle size and dispersion medium on surface plasmon resonance of silver nanoparticles. J. Phys. 32, 145302 (2020)

41. V.K. Singh, B. Bhattacharya, S. Shukla, P.K. Singh, New solid-polymer-electrolyte material for dye-sensitized solar cells. Mater Tehnol. 49, 123–127 (2015)

42. M. Ravi, Y. Pavan, K. Kiran Kumar, S. Bhuvani, A.K. Sharma, V.V.R. Narasimha Rao, Studies on electrical and dielectric properties of PVP:KBr O4 complexed polymer electrolyte films. Mater. Chem. Phys. 130, 442–448 (2011)

43. K. Kamaruddin, D. Edikresnha, I. Sriyanti, M.M. Munir, K. Dain, D. Chattopadhyay, Effect of poly (vinyl pyrrolidone) on the morphology and physical properties of poly (vinyl alcohol)/sodium montmorillonite nanocomposite films. Prog. Nat. Sci. 23, 579–587 (2013)

44. A.A. Menazea, A.M. Ismail, N.S. Awwad, H.A. Ibrahim, Physical characterization and antibacterial activity of PVA/Chitosan matrix doped by selenium nanoparticles prepared
via one-pot laser ablation route. J. Market Res. 9, 9598–9606 (2020)
45. H. Zidan, N. El-Ghamaz, A. Abdelghany, A. Lotfy, Structural and electrical properties of PVA/PVP blend doped with methylene blue dye. Int. J. Electrochem. Sci. 11, 9041–9056 (2016)
46. K. Jyoti, M. Baunthiyal, A. Singh, Characterization of silver nanoparticles synthesized using Urtica dioica Linn. leaves and their synergistic effects with antibiotics. J. Radiat. Res. Appl. Sci. 9, 217–227 (2016)
47. A.M. Abdelghany, A.A. Menazea, A.M. Ismail, Synthesis, characterization and antimicrobial activity of Chitosan/Poly-vinyl alcohol blend doped with Hibiscus Sabdariffa L. extract. J. Mol. Struct. 1197, 603–609 (2019)
48. H.H. Saleh, D.E. El-Hadedy, G.A. Meligi, T.A. Afiify, Synthesis, characterization and antibacterial activity of Ag/PVA nanocomposite. J. Sci. Res. 5, 151–160 (2013)
49. D. Fink, Fundamentals of Ion-Irradiated Polymers (Springer-Verlag, Heidelberg, 2004)
50. M.S. Mehata, Surface plasmon resonance allied applications of silver nanoflowers synthesized from Breynia vitis-idaea leaf extract. Dalton Trans. 51, 2726–2736 (2022)
51. E. Saion, E. Gharibshahi, K. Naghavi, Size-controlled and optical properties of monodispersed silver nanoparticles synthesized by the radiolytic reduction method. Int. J. Mol. Sci. 14, 7880–7896 (2013)
52. J. Tauc, R. Grigorovici, A. Vancu, Optical properties and electronic structure of amorphous germanium. Physica stat. solidi (b) 15, 627–637 (1966)
53. R. Murri, L. Schiavulli, N. Pinto, T. Ligonzo, Urbach tail in amorphous gallium arsenide films. J. Non-Cryst. Solids 139, 60–66 (1992)
54. F. Urbach, The long-wavelength edge of photographic sensitivity and of the electronic absorption of solids. Phys. Rev. 92, 1324–1324 (1953)
55. M.A. Quinteros, V.C. Aristizábal, P.R. Dalmasso, M.G. Paraje, P.L. Páez, Oxidative stress generation of silver nanoparticles in three bacterial genera and its relationship with the antimicrobial activity. Toxicol. Vitro 36, 216–223 (2016)

Publisher’s Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.