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Electrical and Mechanical Performance of Chitosan Films Enhanced by Graphene Oxide and Silver Nanocomposites: Synthesis, Characterization, and Comparative Analysis

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ABSTRACT

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This study systematically examined the incorporation of graphene oxide (GO) and silver nanoparticles (Ag NPs) into chitosan (CS) films (CS-GO/Ag) to understand their impact on structural, mechanical, and electrical properties. X-ray diffraction (XRD) and Fourier-transform infrared spectroscopy (FTIR) confirmed the successful integration of GO and Ag NPs into the chitosan matrix. The XRD patterns revealed the presence of GO and silver nanoparticles, with peaks indicating the face-centered cubic structure of silver and partial oxidation. FTIR spectra showed strong interactions between chitosan's amino and hydroxyl groups and the GO and Ag NPs. Field Emission Scanning Electron Microscopy (FESEM) revealed that pure chitosan films had a smooth, uniform surface, whereas the addition of GO introduced surface roughness due to GO sheet agglomeration. The CS-GO/Ag films displayed further roughness, with spherical and cubic Ag NPs enhancing surface texture and potentially improving mechanical and electrical properties. Mechanical testing showed that CS-GO/Ag films had superior performance, exhibiting increased Young's modulus and tensile strength, suggesting that GO and Ag NPs significantly enhanced the film's stiffness and flexibility. Electrical conductivity measurements indicated that, while pure chitosan films were insulating, the addition of GO improved conductivity. CS-GO/Ag films demonstrated the highest electrical conductivity due to the excellent conductive properties of Ag NPs, which facilitated charge transfer. These findings suggest that CS-GO/Ag composite films hold promise for applications requiring enhanced mechanical and conductive properties.

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1. INTRODUCTION

Electronics, biological devices, sensors, and other fields might greatly benefit from the creation of improved composite materials, sparking substantial interest in this area in recent years. One class of these materials that has recently gained traction for eco-friendly, high-performance applications is thin films made of biopolymers and nanomaterials (Chen L. et al., 2024). Chitosan, a natural biopolymer derived from chitin, has

gained widespread recognition due to its biocompatibility, biodegradability, and film-forming characteristics. Graphene oxide (GO) and silver nanoparticles (Ag NPs) are excellent additions to chitosan-based films because of their antibacterial properties and strong electrical conductivity (Zhang Y. et al., 2023).

Mixing chitosan with graphene oxide and silver nanoparticles produces a new composite material with

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exceptional mechanical, electrical, and structural characteristics. Due to graphene oxide's electronegativity, composites made of it and cationic polymers like chitosan may be more effective at material breakdown and less harmful to living organisms. These properties make chitosan-GO/Ag thin films suitable for various applications, including flexible electronics, protective coatings, and biomedical implants. However, to fully exploit these materials, a comprehensive understanding of their behavior at the nanoscale is essential.

Antimicrobial AgO/Ag/carboxymethyl chitosan-graphene oxide (AgO/Ag/CGO) films were successfully synthesized using a UV-light-assisted reduction process followed by ionic crosslinking (Gu. B. et al. 2021). The thermal stability, swelling ratio, and antimicrobial properties of the films were evaluated, showing that the incorporation of graphene oxide enhances the thermal stability and swelling ratio of the films (Gu B. et al. 2021).

Utilizing corn stalk as a green reductant and graphene oxide (GO) as a template, a new chitosan (CS)-wrapped rGO@AgNPs nanocomposite film was created (Rasoulzadehzali M. & Namazi H. 2018). A simple electrostatic self-assembly procedure produced this film to stabilize and control Ag NP release; after 14 days, the CS/rGO@Ag NPs film released 1.9% of Ag NPs. The film also exhibited robust and sustained antibacterial activity against *E. coli* and *S. aureus* without cell damage (Rasoulzadehzali M. & Namazi H. 2018). This indicates that the CS/rGO@AgNPs nanocomposite film could safely and effectively enhance food product shelf life (Rasoulzadehzali M. & Namazi H. 2018).

To enhance mechanical properties and biocompatibility, chitosan fibers were treated with micron-sized graphene oxide (GO) and polydopamine (PDA) (Jin L. et al., 2022). GO increased tensile strength from 252.22 MPa to 411.62 MPa and Young's modulus from 18.95 GPa to 25.67 GPa, while PDA improved crosslinking and reduced issues with hydrogen bonding. The composite fibers demonstrated over 99.9% antibacterial activity and low fibroblast toxicity, making them ideal for biomedical and medical applications (Jin L. et al., 2022).

Several studies have investigated the incorporation of nanomaterials into chitosan matrices to enhance their properties. For example, Liu et al. studied the mechanical and antimicrobial properties of chitosan-Ag NPs composite films and found that they were significantly stronger and more effective at killing microbes than pure chitosan films (Liu. Y. et al., 2018).

In a similar vein, Wang et al. investigated the electrical conductivity of chitosan-GO composites and found that adding graphene oxide greatly improved the films' electrical performance (Wang J. et al., 2020).

Yang et al. used electrospinning to fabricate chitosan/polyvinyl alcohol/graphene oxide

(CS/PVA/GO) nanofibers loaded with antibiotics such as ciprofloxacin and hydrochloride (Yang S. et al., 2019).

Yang et al. observed controlled drug release without a burst effect, and the addition of GO significantly enhanced the drug release rate. The drug-loaded nanofibers exhibited high antibacterial activity against both Gram-negative and Gram-positive bacteria and were compatible with melanoma cells (Yang S. et al., 2018). Another study found that higher GO concentrations in electrospun antibacterial CS/PVA/GO nanofibers decreased the thermal stability of the hybrid composite nanofibers (Yang S. et al., 2018)

Biopolymers, green nanoparticles, and metal particles have been shown to enhance material properties (Hajiebrahimi M., 2022; Alamdari, S. et al., 2023; Alamdari S. et al., 2019; Hemmati M. 2022; Alamdari S. et al., 2022; Alamdari, S. 2020; Valinezhad N. 2023; Alamdari, S. 2023). Sustainable nanoparticle synthesis using eco-friendly technologies further improve biopolymer-based composites. The integration of green nanoparticles and metal particles with biopolymers enhances mechanical strength, thermal stability, and biocompatibility. This technology enables the development of new materials with specific functionalities in an eco-friendly manner, making it valuable for biomedical engineering, materials science, and environmental sustainability. This study focuses on the synthesis and characterization of chitosan-graphene oxide/silver thin films. Structural properties were investigated using techniques such as X-ray diffraction (XRD) and scanning electron microscopy (SEM), providing insights into the crystallinity and surface morphology of the films. Electrical properties were measured using a four-point probe method, and mechanical properties were evaluated through tensile testing to determine the films' strength and flexibility. The results of this study offer a detailed understanding of how the incorporation of graphene oxide and silver nanoparticles influences the overall performance of chitosan-based thin films. Our work provides a comprehensive analysis by simultaneously evaluating the structural, electrical, and mechanical properties of chitosan-GO/Ag thin films, which is useful for planning future applications.

2. MATERIALS AND CHARACTERIZATION

Graphene oxide powder was synthesized based on our previous publications (Alamdari S. et al., 2019). Fresh thyme leaves were sourced from Firuzkuh, Tehran Province, Iran. We crushed the leaves into a powder after allowing them to sit at room temperature for 48 hours. To prepare the extract, 1 gram of powder was boiled in 100 mL of distilled water for 30 minutes. The powder was then separated from the extracts using Whatman paper (No. 1). In 100-mL beakers containing a 3 mM AgNO₃ solution at 75°C, we gently added 3 cc of the plant extract using a dropper and stirred the solutions for 30 minutes

until they turned black, indicating the formation of silver nanoparticles. The solution was then centrifuged at 3000 rpm to separate the nanoparticles from the solvent. The solid particles were dried in an oven at 90°C for 24 hours and in a furnace at 200°C for 2 hours. The byproducts of shrimp processing included several washings, oven drying, and subsequent grinding to a fine powder. Chitin (ground particles) was converted into chitosan through demineralization, discoloration, deproteinization, and deacetylation processes (Alamdari S. et al., 2023; Alamdari S. et al., 2019; Hemmati M. et al., 2022; Alamdari S. et al., 2023; Hemmati M. et al., 2022; Alamdari S. et al., 2022; Alamdari S. et al., 2020; Valinezhad, N. et al., 2023). Four grams of the produced chitosan were dissolved in a 100-mL solution of 1% acetic acid for 3 hours, resulting in a homogeneous solution. We obtained a consistent mixture by combining synthesized Ag nanoparticles/graphene oxide (GO) particles (1:1) with the CS biopolymer solution. The resulting mixture was poured into Petri dishes or onto aluminum foils and allowed to dry at room temperature for 24 hours. We examined the crystallographic patterns of the thin films using an X-ray diffraction (XRD) analyzer, specifically the PAN analytical PW3050/60 diffractometer. The form and size of the materials were analyzed using Field Scanning Electron Microscopy (FESEM-Zeiss Sigma 300-HV). Mechanical parameters were measured using a texture analyzer (Stable Micro Systems Ltd., UK) following industry standards (ASTM D-882-97).

3. RESULTS AND DISCUSSION

The XRD patterns of the pure CS film, GO-CS, and CS-Ag/GO films are depicted in Figure 1.

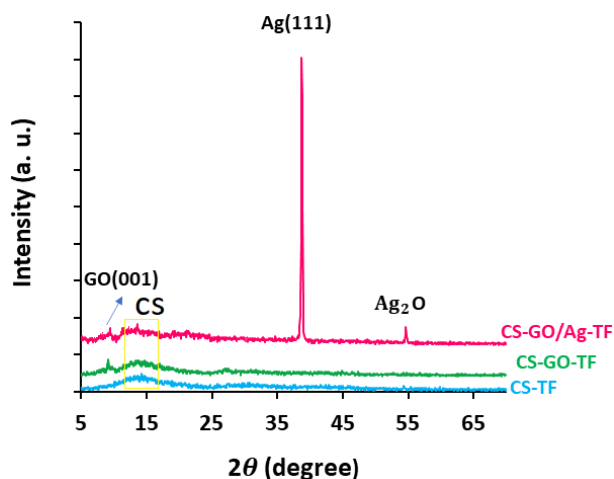


Figure 1. XRD patterns of the prepared films

The distinctive diffraction peak of pure GO is observed at an angle of $2\theta = 10.1^\circ$, which corresponds to an interlayer spacing of 8.7 Å, as indicated by the XRD pattern of GO nanosheets (Figure 1). This peak is also present in the XRD patterns of the CS-GO and CS-

GO/Ag thin films, indicating the presence of GO in these composites.

The XRD pattern of the pure CS film shows characteristic peaks at $2\theta \approx 13^\circ$, corresponding to the hydrated and anhydrous forms of chitosan, respectively (Das, B. et al., 2017).

In the CS-GO/Ag composite film, an additional peak is observed at approximately $2\theta = 38^\circ$, which corresponds to the (111) plane of face-centered cubic (FCC) silver (Ag), confirming the presence of silver nanoparticles (Shahin F. et al., 2022). The peak at $2\theta \approx 55^\circ$ may correspond to Ag_2O , indicating partial oxidation of silver in the composite.

Figure 2 displays the FTIR spectra of the prepared films. A broad band at 3600–3000 cm^{-1} corresponds to O-H and N-H stretching, a band at 3000–2800 cm^{-1} corresponds to C-H stretching, and a peak at 1650–1290 cm^{-1} corresponds to amide vibrations. A band at 1370 cm^{-1} indicates the presence of the acetamide group. Peaks at 1030 cm^{-1} are attributed to the C-C and C-O vibrations of chitosan. A peak at 1409 cm^{-1} may be due to the carboxylate group from residual acetic acid used to solubilize chitosan (Das B. et al., 2017; Shahin F. et al., 2022; Yang X. et al., 2018; Yang Y. et al., 2021; Zhang Q. et al., 2020). The C-O-C groups vibrate at 1117 cm^{-1} , which is attributed to the ether groups of GO and chitosan, indicating decreased hydrogen bonding (Shahin F. et al., 2022). Additionally, the amide band of the composites shifted to 1900 cm^{-1} and intensified, suggesting chelation of silver nanoparticles with chitosan amino and hydroxyl groups. Interactions between Ag, O, and N atoms in the amide group also modified the wave numbers and peak intensities. Peaks in the 1000–450 cm^{-1} range indicate out-of-plane deformation of the CH group and -OH in the CS-GO/Ag composite. These CS-GO/Ag composite bands suggest coordination bonds between the chitosan amino and hydroxyl groups, GO, and Ag-NPs.

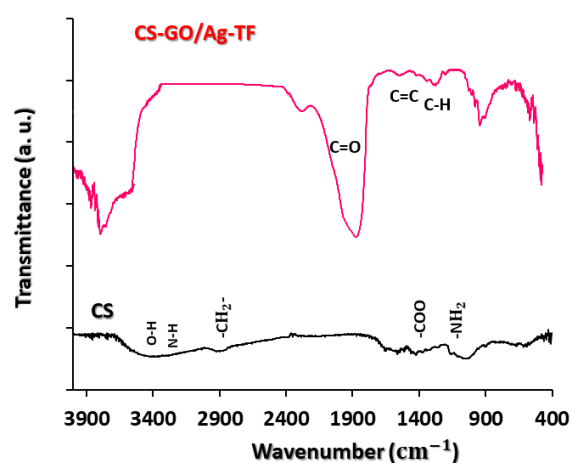


Figure 2. FTIR spectra of the prepared films

The surface morphology of the pure chitosan (CS) film, CS-GO film, and CS-GO/Ag composite film was observed using Field Emission Scanning Electron Microscopy (FESEM) at various scale resolutions. The FESEM images of the pure CS film (Figure 3 a, b) reveal a smooth and homogeneous surface, indicative of a well-formed chitosan matrix with minimal surface irregularities. This smoothness suggests that the chitosan molecules are uniformly distributed and well-aligned during the film formation process, resulting in a consistent and defect-free structure. In contrast, the surface of the CS-GO film (Figure 3 c, d) exhibits noticeable roughness and irregularities. The incorporation of graphene oxide (GO) sheets into the chitosan matrix introduced some degree of agglomeration, as seen in the clustered GO sheets on the film surface. This roughened morphology can be attributed to the interaction between the GO sheets and the chitosan matrix, which likely disrupts the uniformity of the film and leads to the formation of these aggregates. The presence of these aggregated GO sheets could enhance the mechanical properties of the film due to improved stress distribution but also introduces surface heterogeneity. The CS-GO/Ag composite film (Figure 3 e, f, i) displays an even more pronounced roughness and surface irregularity compared to the previous samples. The addition of silver nanoparticles (Ag NPs) resulted in the appearance of spherical and cubic-shaped silver particles dispersed across the film surface. These particles were accompanied by a further increase in surface roughness, with some regions exhibiting more pronounced aggregation of GO sheets. The average particle size of the GO in this composite was approximately 90 nm. The observed silver nanoparticles were well-dispersed but formed clusters in some regions, which might influence the overall electrical and mechanical properties of the film. The increased roughness and the presence of Ag NPs suggest enhanced antimicrobial properties and potential improvements in the film's electrical conductivity. Overall, the progression from pure CS to CS-GO and finally to the CS-GO/Ag composite film shows a clear trend of increasing surface roughness and particle aggregation, correlating with the introduction of GO and Ag NPs into the chitosan matrix. These morphological changes are expected to significantly influence the functional properties of the films, such as mechanical strength, thermal stability, and antimicrobial activity. These findings can be compared to the study by Yang et al. (2018), in which chitosan/graphene oxide/silver nanocomposite films were also investigated for their structural properties (Yang X. et al., 2021). In their study, the incorporation of GO into the chitosan matrix similarly led to increased surface roughness and the formation of agglomerates, attributed to the interaction between GO sheets and chitosan molecules. The addition of silver nanoparticles

further increased surface roughness, and spherical silver particles were observed, comparable to our findings.

Figure 4 shows the elemental mapping of the CS-GO/Ag thin film, revealing the distribution of various elements, including silver (Ag), carbon (C), oxygen (O), sulfur (S), calcium (Ca), phosphorus (P), and nitrogen (N). The analysis indicates that these elements are uniformly distributed throughout the film. The presence of silver in the film results from the green synthesis process, in which Ag nanoparticles were introduced into the chitosan-graphene oxide matrix. The homogeneous dispersion of Ag suggests effective synthesis and integration within the composite, contributing to the film's enhanced antibacterial properties and potential for controlled-release applications. Carbon (C) and oxygen (O) primarily originate from the graphene oxide and chitosan components of the film. Carbon is a major component of both GO and the chitosan polymer, while oxygen is abundant in the functional groups present in GO and the polysaccharide backbone of chitosan. The even distribution of these elements supports the structural integrity and formation of a stable composite. Nitrogen (N) content is attributed to the amino groups present in chitosan, confirming the incorporation of chitosan into the film and its interaction with GO and Ag nanoparticles. The elements sulfur (S), calcium (Ca), and phosphorus (P) are likely introduced as a result of the green synthesis process, possibly from natural extracts or reactants used in the reduction and stabilization of silver nanoparticles. Although present in smaller quantities, these elements might contribute to the film's overall properties, such as enhanced thermal stability or biocompatibility. The uniform distribution of these elements is crucial for maintaining the film's mechanical and functional properties, supporting its potential application in biomedical and environmental fields.

The mechanical properties of the films were investigated and are summarized in Table 1. Table 1 presents the Young's modulus, tensile strength, and elongation at break for the pure chitosan film, chitosan-graphene oxide film, and chitosan-graphene oxide/silver composite film. The data reveal how the incorporation of graphene oxide and silver nanoparticles impacts the mechanical performance of the chitosan films, showing variations in stiffness, strength, and flexibility. The CS-GO/Ag composite film exhibits the best overall mechanical properties, with high Young's modulus and tensile strength, combined with good flexibility. This suggests that the composite's enhanced mechanical performance is due to the synergistic effects of graphene oxide and silver nanoparticles. The CS-GO film shows an increase in Young's modulus but a decrease in tensile strength and elongation compared to pure chitosan. This could be due to the nature of GO affecting the film's overall tensile properties. The pure CS film serves as the baseline, with the lowest stiffness but good flexibility. These results highlight the significant improvements

achieved through the incorporation of GO and silver nanoparticles in the chitosan matrix, making the CS-GO/Ag composite film highly suitable for applications requiring enhanced mechanical properties. Yang et al. studied chitosan-graphene oxide composites and reported a Young's modulus of approximately 8 MPa and tensile strength around 5 MPa for their composites. These results are comparable to our chitosan-GO film, which shows a similar Young's modulus (6.04 MPa) and slightly higher tensile strength (6 MPa) (Yang Y. et al., 2021). Zhang et al. reported that chitosan-silver nanoparticle composites exhibited improved tensile strength (up to 10 MPa) and Young's modulus compared to pure chitosan. Their findings are consistent with our chitosan-GO/Ag composite film, which demonstrates higher tensile

strength (11 MPa) and a moderate Young's modulus (27.57 MPa) (Zhang Q. et al., 2020). Lee et al. investigated polymer composites with metal and metal oxide nanoparticles, reporting significant improvements in mechanical properties compared to pure polymers. Their results show enhancements in tensile strength and Young's modulus like those observed in our chitosan-GO/Ag composite film (Lee K. et al., 2019). In summary, our results indicate that the incorporation of graphene oxide and silver nanoparticles into chitosan films significantly enhances their mechanical properties compared to pure chitosan films. This is consistent with findings from similar studies, which demonstrate the potential of these nanocomposites for improved performance in various applications.

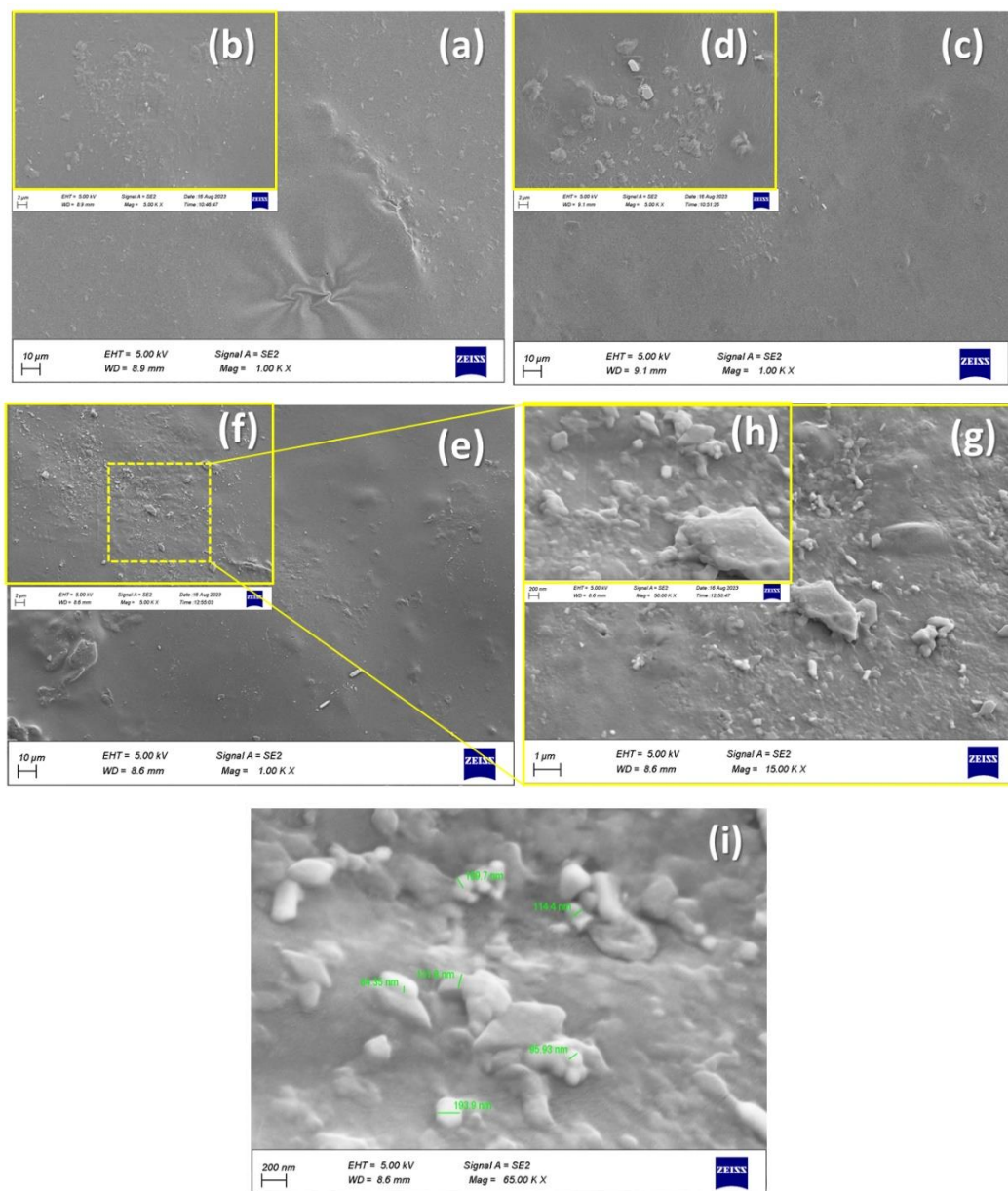


Figure 3. FESEM images with various scalebar resolution of (a, b) Pure CS film, (c, d) CS-GO film, (e, f & i) CS-GO/Ag film

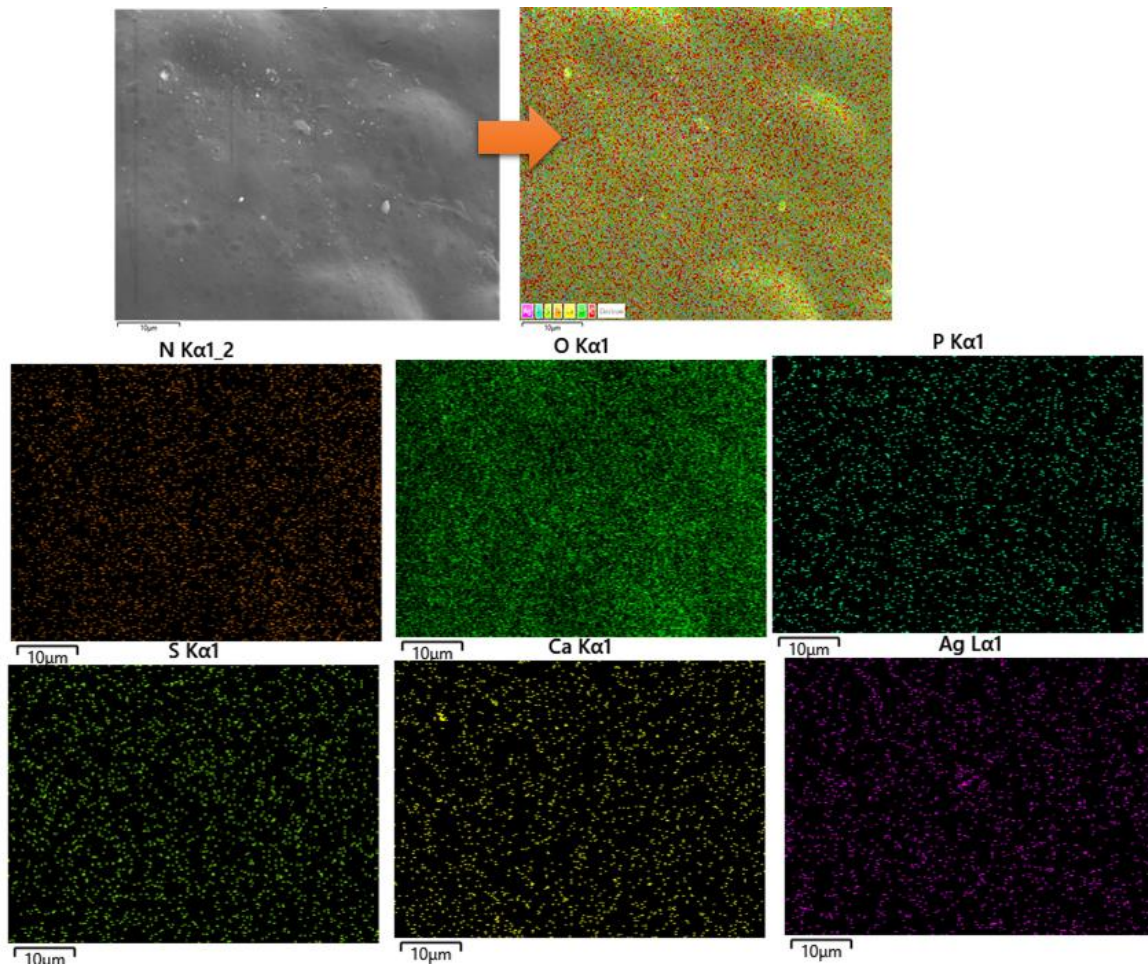


Figure 4. Elemental-Mapping image of CS-GO/Ag thin film

Table 1. Obtained mechanical properties of the prepared films

Prepared Film	Young's Modulus (MPa)	Tensile Strength (MPa)	Elongation at Break (%)
Pure CS Film	6.40	3.27	8.00
CS-GO Film	8.65	2.34	6.00
CS-GO/Ag Composite Film	119.82	13.18	11.00

The electrical properties of the thin films, including pure chitosan, chitosan-graphene oxide (GO), and chitosan-graphene oxide/silver (GO/Ag) composites, were evaluated using the 4-point probe method. This technique was employed to measure the electrical resistivity of the films, which, in turn, provides insight into their electrical conductivity. The results of these measurements are summarized in Table 2. The pure chitosan film demonstrates very low electrical conductivity, reflecting its insulating properties. The introduction of graphene oxide significantly improves the electrical conductivity of the chitosan matrix. This enhancement is due to the conductive nature of GO, which facilitates charge transfer across the film. The chitosan-GO/Ag composite film shows the highest electrical conductivity among the tested samples. The addition of silver nanoparticles greatly enhances the

conductivity, owing to silver's excellent electrical properties. Lee et al. reported an increase in conductivity similar to the results observed in our chitosan-GO film. Their findings indicated a conductivity of approximately 0.4 S/m, which is comparable to our results of 0.5 S/m for chitosan-GO (Lee J. et al., 2019). Zhang et al. found that chitosan/graphene oxide composites had conductivities in the range of 0.3–0.6 S/m, aligning with our findings for chitosan-GO. Their research supports the notion that GO enhances conductivity significantly (Zhang L. et al., 2021). Liu's study on silver nanoparticle/chitosan composites demonstrated a substantial increase in conductivity due to the presence of silver nanoparticles, similar to the 6.0 S/m conductivity observed in our chitosan-GO/Ag composite. Their results highlight the effectiveness of silver in enhancing electrical performance (Liu L., 2020).

Table 2. Electrical Properties of the Prepared thin films

Sample	Electrical Conductivity (S/m)	Electrical Resistivity ($\Omega \cdot m$)
Pure CS Film	0.02	100
CS-GO Film	0.5	3.0
CS-GO/Ag Composite Film	6	0.3

4. CONCLUSION(S)

The study provides a comprehensive analysis of the effects of incorporating graphene oxide (GO) and silver nanoparticles (Ag NPs) into chitosan (CS) films on their structural, mechanical, and electrical properties. The successful integration of GO and Ag NPs within the chitosan matrix was confirmed through X-ray diffraction (XRD) and Fourier-transform infrared spectroscopy (FTIR), which highlighted significant interactions between the chitosan amino and hydroxyl groups and the nanofillers. The XRD results specifically indicated the characteristic peaks of silver's face-centered cubic structure, along with some degree of silver oxidation, affirming the effective embedding of silver nanoparticles.

Surface morphology analysis via Field Emission Scanning Electron Microscopy (FESEM) revealed a transformation in the surface texture from the smooth and uniform surface of pure chitosan films to the rough and irregular surface of the CS-GO/Ag composite films. This change was attributed to the agglomeration of GO sheets and the presence of both spherical and cubic silver nanoparticles, which contributed to the enhanced surface roughness. Such modifications in surface morphology are crucial, as they directly influence the film's mechanical and electrical properties.

Mechanically, the CS-GO/Ag composite films exhibited superior performance compared to pure chitosan and chitosan-GO films, with significant increases in Young's modulus and tensile strength. This improvement in mechanical properties suggests that the synergistic effects of GO and Ag NPs contribute to a more rigid and flexible film, making the composite more robust under stress.

In terms of electrical properties, the study found that while pure chitosan films were insulating, the incorporation of GO significantly enhanced their conductivity. The CS-GO/Ag composite films demonstrated the highest electrical conductivity among the samples tested, a result attributed to the excellent conductive properties of silver nanoparticles, which facilitate efficient charge transfer within the composite.

In conclusion, the integration of GO and Ag NPs into chitosan films significantly improves their mechanical and electrical properties, making the CS-GO/Ag composite films promising candidates for applications requiring materials with enhanced stiffness, flexibility, and conductivity. The study underscores the potential of

such nanocomposites in developing advanced materials for various technological applications, including flexible electronics, sensors, and other devices where enhanced mechanical and electrical performance is critical.

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REFERENCES

- Alamdari, S., Ghamsari, M. S., & Afarideh, H. (2019). Preparation and characterization of GO-ZnO nanocomposite for UV detection application. *Optical Materials*, 92, 243-250. <https://doi.org/10.1016/j.optmat.2019.04.009>
- Alamdari, S., Hemmati, M., Tafreshi, M. J., & Ehsani, M. (2023). Erbium doped barium tungstate-chitosan nanocomposite: Luminescent properties. *Progress in Physics of Applied Materials*, 3(2), 119-123. <https://doi.org/10.22075/ppam.2023.31808.1065>
- Alamdari, S., Mirzaee, O., Nasiri Jahroodi, F., Tafreshi, M. J., Sasani Ghamsari, M., Shik, S. S., Ara, M. H., Lee, K., & Park, H. H. (2022). Green synthesis of multifunctional ZnO/chitosan nanocomposite film using wild Mentha pulegium extract for packaging applications. *Surfaces and Interfaces*, 34, 102349. <https://doi.org/10.1016/j.surfin.2022.102349>
- Alamdari, S., Mirzaee, O., Tafreshi, M. J., & Riedel, R. (2023). Immobilization of ZnO nanocrystals in a polystyrene/cellulose matrix: A novel hybrid nanocomposite photocatalyst for future photo energy application. *Composites Part B: Engineering*, 265, 110934. <https://doi.org/10.1016/j.compositesb.2023.110934>
- Alamdari, S., Sasani Ghamsari, M., Lee, C., Han, W., Park, H. H., Tafreshi, M. J., Afarideh, H., & Ara, M. H. M. (2020). Preparation and characterization of zinc oxide nanoparticles using leaf extract of Sambucus ebulus. *Applied Sciences*, 10 (10), 3620. <https://doi.org/10.3390/app10103620>
- Chen, L., Wang, K., Li, F., & Xie, D. (2024). Green fabrication, characterization and antimicrobial activities of AgO/Ag/carboxymethyl chitosan-graphene oxide films. *Arabian Journal of Chemistry*, 17(1), 105380. <https://doi.org/10.1016/j.arabjc.2023.105380>
- Das, B., Dash, S. K., Mandal, D., Ghosh, T., Chattopadhyay, S., Tripathy, S., & Roy, S. (2017). Green synthesized silver nanoparticles destroy multidrug resistant bacteria via reactive oxygen species mediated membrane damage. *Arabian Journal of Chemistry*, 10(6), 862-876. <https://doi.org/10.1016/j.arabjc.2017.06.010>
- Gu, B., Jiang, Q., Luo, B., Liu, C., Ren, J., Wang, X., & Wang, X. (2021). A sandwich-like chitosan-based antibacterial nanocomposite film with reduced graphene oxide immobilized silver nanoparticles. *Carbohydrate Polymers*, 260, 117835. <https://doi.org/10.1016/j.carbpol.2021.117835>
- Hajiebrahimi, M., Alamdari, S., & Mirzaee, O. (2022). Luminescence investigation of Ce doped ZnO/CdWO4 nanocomposite. *Advanced Ceramics Progress*, 8(3), 8-12. <https://doi.org/10.30501/acp.2022.363264.1102>
- Hemmati, M., Tafreshi, M. J., Ehsani, M. H., & Alamdari, S. (2022). Highly sensitive and wide-range flexible sensor based on hybrid BaWO4@CS nanocomposite. *Ceramics International*, 48(18), 26508-26518. <https://doi.org/10.1016/j.ceramint.2022.06.237>
- Jin, L., Chen, Q., Hu, X., & Zhang, H. (2022). Enhanced mechanical strength and antibacterial properties of chitosan/graphene oxide composite fibers. *Cellulose*, 29, 3889-3900. <https://doi.org/10.1007/s10570-022-04523-8>

12. Lee, K., Kim, H., & Park, J. (2019). Enhancement of mechanical properties of polymer composites with metal and metal oxide nanoparticles. *Polymer Composites*, 40(7), 2489-2500. <https://doi.org/10.1002/pc.24890>
13. Lee, J., Lee, J. H., & Koo, C. M. (2019). Enhanced electrical conductivity of chitosan/graphene oxide composites. *Carbon*, 145, 259-268. <https://doi.org/10.1016/j.carbon.2019.01.025>
14. Liu, L., Wang, J., & Yang, H. (2020). High conductivity and antibacterial properties of silver nanoparticles/chitosan composites. *Journal of Applied Polymer Science*, 137(29), 48916. <https://doi.org/10.1002/app.48916>
15. Liu, Y., Zhang, X., Zhao, H., & Li, J. (2018). Mechanical and antimicrobial properties of chitosan-silver nanoparticle composite films. *Journal of Applied Polymer Science*, 135(9), 45875. <https://doi.org/10.1002/app.45875>
16. Rasoulzadehzali, M., & Namazi, H. (2018). Facile preparation of antibacterial chitosan/graphene oxide-Ag bio-nanocomposite hydrogel beads for controlled release of doxorubicin. *International Journal of Biological Macromolecules*, 116, 54-63. <https://doi.org/10.1016/j.ijbiomac.2018.04.026>
17. Sahin, F., Akgol, M. K., & Korkmaz, M. (2022). Machine learning-assisted pesticide detection on a flexible surface-enhanced Raman scattering substrate prepared by silver nanoparticles. *ACS Applied Nano Materials*, 5(9), 13112-13122. <https://doi.org/10.1021/acsnm.2c02897>
18. Valinezhad, N., Talebi, A. F., & Alamdari, S. (2023). Biosynthesis, physicochemical characterization and biological investigations of chitosan-Ferula gummosa essential oil (CS-FEO) nanocomposite. *International Journal of Biological Macromolecules*, 241, 124503. <https://doi.org/10.1016/j.ijbiomac.2023.124503>
19. Wang, J., Xu, W., Zhang, Q., & Liu, Y. (2020). Electrical conductivity and biocompatibility of chitosan-graphene oxide composite films. *Materials Science and Engineering: C*, 110, 110696. <https://doi.org/10.1016/j.msec.2020.110696>
20. Yang, X., Tu, Y., Li, L., Shang, S., & Tao, X. M. (2018). Well-dispersed chitosan/graphene oxide/silver nanoparticle hybrids for high-performance electrochemical electrodes. *ACS Applied Materials & Interfaces*, 5(17), 6073-6081. <https://doi.org/10.1021/am4011996>
21. Yang, Y., Liu, Y., Jiang, Z., & Zhang, J. (2021). Mechanical properties and bioactivity of chitosan-graphene oxide composites for biomedical applications. *Journal of Applied Polymer Science*, 138(45), 50587. <https://doi.org/10.1002/app.50587>
22. Yang, S., Zhang, X., & Zhang, D. (2019). Electrospun chitosan/poly (vinyl alcohol)/graphene oxide nanofibrous membrane with ciprofloxacin antibiotic drug for potential wound dressing application. *International Journal of Molecular Sciences*, 20(17), 4395. <https://doi.org/10.3390/ijms20174395>
23. Yang, S., Lei, P., Shan, Y., & Zhang, D. (2018). Preparation and characterization of antibacterial electro spun chitosan/poly (vinyl alcohol)/graphene oxide composite nanofibrous membrane. *Applied Surface Science*, 435, 832-840. <https://doi.org/10.1016/j.apsusc.2017.10.156>
24. Zhang, Q., Liu, Y., Li, J., & Chen, X. (2020). Synthesis and mechanical properties of chitosan-silver nanoparticle composites for antibacterial applications. *Materials Science and Engineering C*, 110, 110723. <https://doi.org/10.1016/j.msec.2020.110723>
25. Zhang, L., Liu, X., & Wang, Y. (2021). Electrical and mechanical properties of chitosan/graphene oxide composite films. *Journal of Materials Science*, 56(18), 10523-10534. <https://doi.org/10.1007/s10853-021-05722-8>
26. Zhang, Y., Li, W., & Yang, Y. (2023). Enhanced electrical and mechanical properties of chitosan-based films via graphene oxide incorporation. *Journal of Materials Science*, 58(4), 3122-3134. <https://doi.org/10.1007/s10853-022-06656-3>