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Research article

Development and evaluation of silver-infused Biopolymer coated cotton wound dressings as possible wound healing material

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ABSTRACT

Wound management is a critical clinical issue, with substantial economic and social implications. Traditional dressings often lead to poor healing, impacting the effective wound repair is an ongoing challenge. So, this research aimed to investigate the development of a novel medical textile auxiliary in the form of a padded cotton bandage coated with a blend of agricultural biopolymers (xanthan gum and gum arabic) containing AgNPs with an emphasis on environmental friendliness and sustainability. The samples treated with various biopolymer blend compositions that were assessed by SEM and FTIR analysis, tensile strength, antibacterial properties, and comfort attributes, including air permeability and wicking. Antibacterial tests showed no bacterial growth on the samples, with the maximum inhibition zone measuring 3.3 mm. The mechanical and comfort tests revealed that the blend with 0.5 % xanthan gum and 1 % Arabic gum achieved the highest air permeability at 500 mm/s, the sample with the highest GSM demonstrated superior tensile strength at 42 N, and the 50 GSM sample exhibited better-wicking properties, reaching up to 1.33 cm, compared to the 100 GSM samples. This research is aimed to develop biopolymer-based cotton bandages with improved air permeability, antibacterial, tensile strength, moisture-wicking.

1. Introduction

Accidental injuries and negligence can result in open wounds, increasing the risk of infection. Effective wound care, including cleaning and the use of medicated bandages, is crucial for healing [1]. However, the emergence of antibiotic-resistant pathogens at the

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injection site can lead to delayed wound healing. Bandages facilitate skin tissue by providing a protective barrier against external damage and infection. Bandages are pivotal in healing because conventional options like bandages, gauze, and cotton pads lack efficiency in pain relief and their contribution to healing. Moreover, these traditional dressings are non-reusable and may contribute to toxicity by promoting the growth of bacteria and other microbes [2].

Cotton is an affordable and biocompatible option for wound dressing, featuring biodegradable properties. While its natural polymer structure offers softness, flexibility, and high-water absorption due to cellulose's hydrogen bonding, pure cotton may offer inadequate support in the healing process. Skin granulation can happen when cotton applied to the wound [3,4]. To speed up the healing process, a moist environment is needed which heals the wound in a better way and reduces the chances of complications. So, this type of environment can be developed using hydrogels in bandages to heal the wound effectively [5].

Hydrogels, a 3-D polymeric network have tremendous characteristics for medical applications such as biodegradability, hydrophilicity, and biocompatibility, and can retain fluid in large quantities in their crosslinked polymer network [6]. The source of hydrogel materials can be natural and synthetic, but natural polymer-based hydrogels are the optimal choice for bandages due to their biocompatibility, lower toxicity, and cost-effectiveness [7–9]. Natural biopolymers such as xanthan gum, Arabic gum, etc. have extensive utilization in cosmetic and medical industries. These polysaccharides are utilized in film coatings, nanoparticle preparation, and various pharmaceutical solutions due to their biodegradability, availability, non-toxicity, and cost-effectiveness compared to synthetic sources [10,11].

Xanthan, a natural polysaccharide, is employed in laboratories to enhance solution viscosity with minimal concentrations. It can be derived from various fermentation sources, including plants, seaweed, and bacteria. Xanthan's chemical structure features a branched polysaccharide backbone of cellobiose with side chains composed of a trisaccharide, enhancing its affinity for water [12].Gum Arabic, alternatively known as gum Sudani, Senegal gum, Indian gum, and gum acacia, is a natural combination of glycoprotein and polysaccharide derived from the acacia Senegal tree using the extrusion method. It is edible and widely utilized as an emulsifier in the food and beverage industry. Its molecular structure includes a branched chain of l-arabinose, l-rhamnose, d-glucuronic acid, and 1,3-linked β-d-galactopyranosyl units.

The emergence of nanotechnology-based systems has generated considerable interest, particularly in the biomedical and pharmaceutical sectors, focusing on disease prevention and treatment, such as in wound healing [13–15]. In addition to nanoparticles, these systems encompass various elements like nanofibers, hydrogels, hydrocolloids, and, more recently, nanohybrids—a fusion of different nanotechnological systems [16,17]. Past literature predominantly focused on the therapeutic aspects of wound dressings during development, with limited attention to renewable and less toxic resources [18]. This proposed research emphasizes sustainable wound dressing development, leveraging the promising benefits of nanoparticles to expedite the wound healing process. Characterizations like SEM and FTIR were employed to examine the product. The study involves impregnating synthesized nanoparticles incorporated biopolymer blends onto cotton bandages (50 & 100 GSM) to assess their physical and mechanical properties (tensile strength, air permeability and wicking etc.) The protection against bacteria was tested to assure that these bandages have built in antibacterial properties due to coating of Ag-Biopolymer blends. This research contributes towards development of novel antibacterial medical textiles that could have a possible future as sustainable wound dressing materials.

2. Materials and method

Gum Arabic and xanthan gum, utilized as biopolymer precursors, were procured from Sigma Aldrich. Silver nitrate salt, employed as a precursor for silver nanoparticles, & DMSO serving as reducing agent was also acquired from Sigma Aldrich. Distilled water and cotton nonwoven (50, 100 GSM) were obtained from the institutional laboratory.

2.1. Experimental factors and their levels

The experiment's design was selected to analyze the effect of biopolymer concentrations and fabric areal density. As per the literature, both parameters significantly affect the properties of any bandage. Table 1 outlines the experimental factors and their corresponding levels, while Table 2 presents the design of experiments developed based on these factors and levels.

2.2. Method

2.2.1. Synthesis of silver nanoparticles

The synthesis of silver nanoparticles (AgNPs) began with preparing an $AgNO_3$ solution. Initially, 0.5 g of $AgNO_3$ was diluted in 50 mL of distilled water and stirred for 30 min at room temperature. Subsequently, the aqueous $AgNO_3$ solution was combined with the reducing agent dimethyl sulfoxide (DMSO) to initiate the formation of Ag nanoparticles. The resulting mixture was blended for 4 h at 80 °C until the appearance of a grayish-orange color of Ag nanoparticle development. Fig. 1 shows the schematic of the synthesis

Table 1
Experimental Factors and their levels.

Factors	Levels	
Xanthan gum/Gum Arabic/Ag- nanoparticles Concentrations (w/v) %	0.5	1
Fabric (GSM)	50	100

Table 2
Design of experiment.

Sr.	Xanthan Gum%	Gum Arabic%	Silver Nano Particles Conc. %	Nonwoven Bandages (GSM)
1	1	1	0.5	50
2	1	0.5	0.5	50
3	0.5	1	0.5	50
4	1	1	0.5	100
5	1	0.5	0.5	100
6	0.5	1	0.5	100
7	1	1	1	50
8	1	0.5	1	50
9	0.5	1	1	50
10	1	1	1	100
11	1	0.5	1	100
12	0.5	1	1	100

process of silver nanoparticles.

2.2.2. *Formulation of polymer blend*

Initially the solution of xanthan gum and arabic gum was prepared separately. 0.5 % w/v solution of xanthan gum and arabic was prepared separately in distilled water for 30 min on a magnetic stirrer at room temperature. By stirring the xanthan gum and gum Arabic solutions for 30 min at 80 °C, a homogeneous biopolymer blend was produced. The Ag nanoparticle solution was then added to the mixture, which was stirred for 30–40 min at 80 °C as shown in Fig. 2.

2.2.3. *Application of Ag-biopolymer onto the cotton fabric*

The Ag-biopolymer was applied to cotton fabric by cutting small pieces out of 100 % nonwoven cotton fabric. After that, for proper coating of the biopolymer solution onto cotton fabric, these pieces were dipped in the Ag-biopolymer solution. The samples were then dried overnight at room temperature and cured for two to 3 min at 103 °C in an oven.

2.3. *Characterization*

2.3.1. *Surface Morphology*

Nova SEM (Scanning electron microscope) was used to analyze the surface of the selected sample before and after the application of Ag-biopolymer blend.

2.3.2. *Fourier transform infrared spectroscopy (FTIR)*

Biopolymers were applied to the cotton fabric surface, and the surface was examined through FTIR spectroscopy. The samples were scanned within the range of 4000 cm^{-1} to 500 cm^{-1}.

2.3.3. *Dynamic light scattering (DSL)*

Dynamic light scattering measurements were conducted using the Zetasizer Nano from Malvern, equipped with a 633 nm HE-NE laser and a maximum output of 4 mW, employing the new backscattering method.

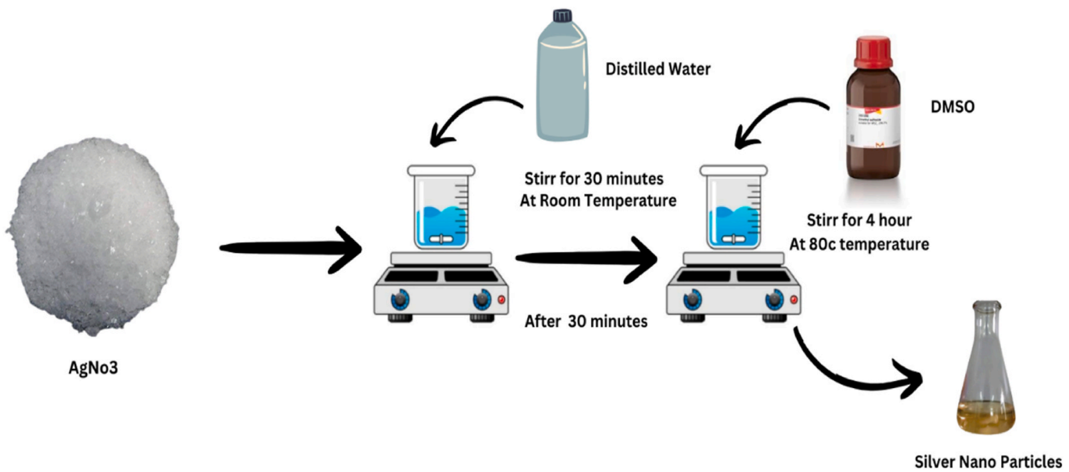

Fig. 1. Schematic diagram to synthesize $AgNO_3$ NPs.

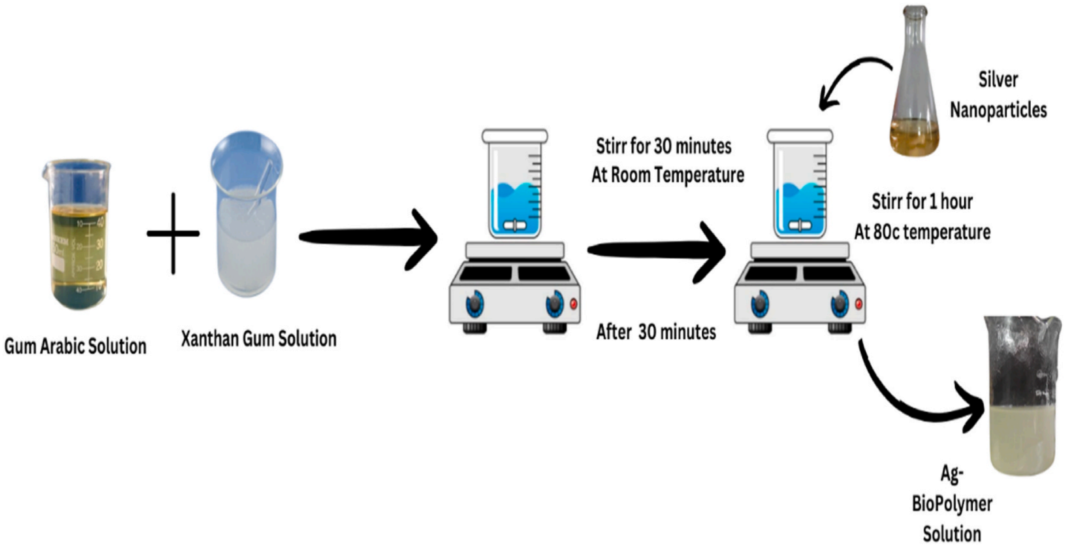

Fig. 2. Schematic diagram to formulate Ag-biopolymer.

2.3.4. *Tensile strength*

The tensile strength of the hydrogel composite was evaluated according to the ISO 13934-2 standard using the grab method. The test involved gripping a 20 cm × 10 cm sample in the jaws and extending it at a constant rate until rupture, with the recorded force at the point of rupture. The testing was conducted at room temperature.

2.3.5. *Air permeability*

The assessment of air permeability (AP) was conducted utilizing an AP tester following the ASTM D737 standard. The pressure and test area parameters used to determine the air permeability of the samples were set at 100 Pa and 20 cm^2, respectively.

2.3.6. *Wicking test*

The assessment of water-wicking speed adhered to the AATCC TM 197–2013 standard. Wicking denotes the dissemination of water across a specified area through capillary action within a material. The samples were suspended vertically throughout the test, with 10 mm immersed in water. Following immersion, the wet area, represented by the wicking height, was gauged from the water level at 5-min intervals.

2.3.7. *Antibacterial test*

The fabricated samples' antimicrobial properties were assessed using the "Agar Disk Diffusion" method with *S. aureus* bacteria as the test organism. Before testing, the samples underwent sterilization in steam at a temperature of 121 °C for 15 min. Subsequently, the sterilized samples were positioned on an agar disk and subjected to an 18-h incubation period, during which the antibacterial efficacy of the samples was observed and analyzed.

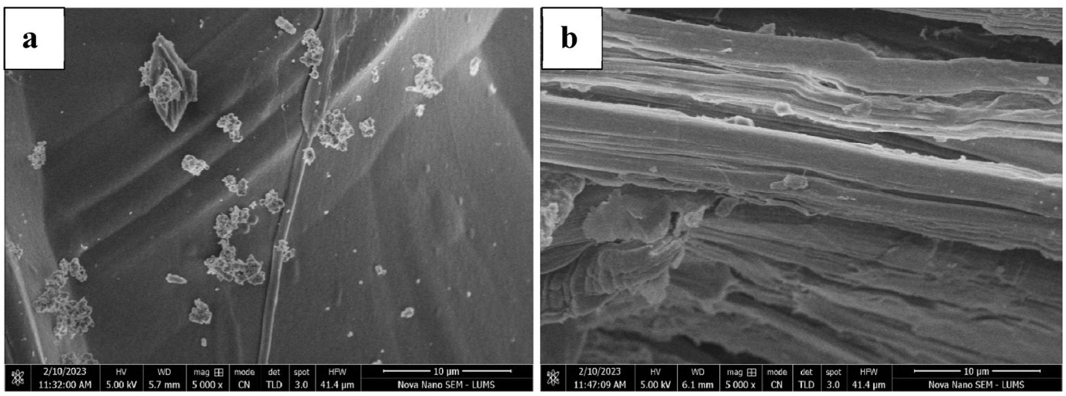

Fig. 3. SEM images of composite samples taken from two distinct locations within the sample.

3. Result and discussion

3.1. Surface morphology

The surface characteristics of the samples were examined through SEM images, as illustrated in Fig. 3. In Fig. 3a, a consistent biopolymer layer is observed covering the fibers. Throughout the image, the biopolymer layer is visible on the surface and between the fibers, presenting a uniform appearance. In contrast, Fig. 3b shows nonwoven fibers not infused with biopolymer blend. Vacant areas and cracks are evident in Fig. 3b, that depict there is major difference in surface of cotton before and after application of Ag-biopolymer blend.

3.2. FTIR analysis

Fourier Transform Infrared Spectroscopy (FTIR) analysis was employed to identify functional groups present in the samples. The FTIR spectra of cotton bandages infused with natural polymers and silver nanoparticles are depicted in Fig. 4. The broad peak observed at 3300 cm^{-1} can be attributed to the OH group, while the appearance of a shoulder peak at 2900 cm^{-1} indicates the -CH stretching [19]. Additionally, the peak at 1644 cm^{-1} signifies the COO-symmetric stretch, and the peak at 1426 cm^{-1} corresponds to the asymmetric stretch of gum Arabic. Notably, the absence of a peak in the 1700 region, typically present in xanthan gum, was observed. The presence of multiple peaks and a complex spectrum collectively indicate the successful impregnation of xanthan gum, gum Arabic blend, and silver nanoparticles onto the cotton bandage.

3.3. Dynamic light scattering (Zeta sizer)

The study employs dynamic light scattering (DLS) to analyze the size distribution of particles or molecules within a water dispenser sample. These measurements were conducted under specific conditions, including the absence of material absorption and a temperature of 25 °C. The Z-average (D.nm) is reported as 494.1 nm, representing the average particle diameter in the sample, as shown in Fig. 5. The intensity distribution reveals three distinct peaks. Peak 1 exhibits a size of 513.9 nm, an intensity of 94.6, and a standard deviation of 119, indicating the presence of particles of approximately 513.9 nm with a relatively high concentration and size variation. Peak 2 showcases particles of 59.20 nm, an intensity of 5.4, and a standard deviation of 6.423, suggesting a lower concentration and smaller size variation than Peak 1. Peak 3, with a size of 0 nm, intensity of 0, and standard deviation of 0, signifies the absence of particles in this size range.

3.4. Tensile strength

Tensile strength, a critical measure of a material's ability to withstand pulling stress before breaking, along with its elongation properties, is influenced by various factors such as fiber properties, areal density, bonding mechanism, and finishing applied to nonwovens. This study focused on twelve samples, six weighing 50 GSM and the remaining six weighing 100 GSM, all sharing the same bonding mechanism and areal density. Standardized test conditions were maintained to compare the two groups' tensile strengths

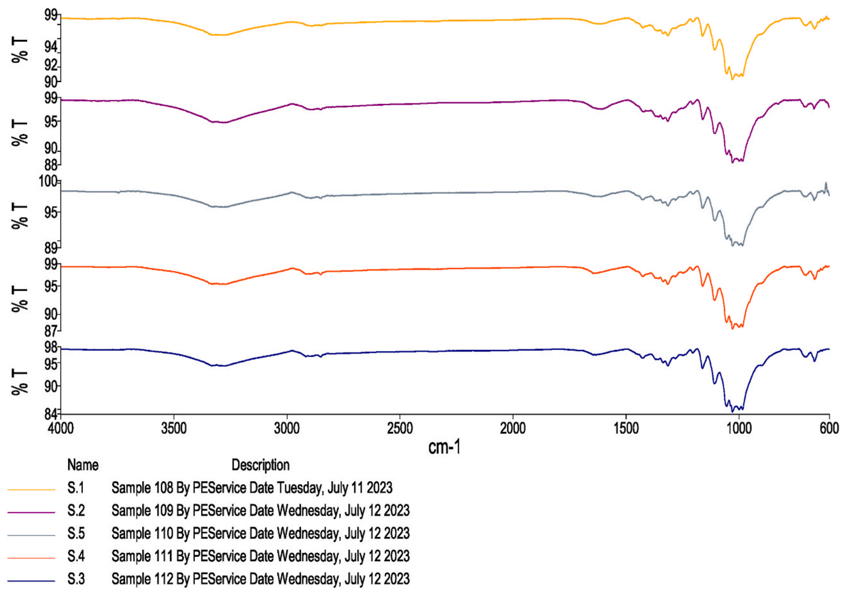

Fig. 4. FTIR analysis of Ag-biopolymer coated bandage.

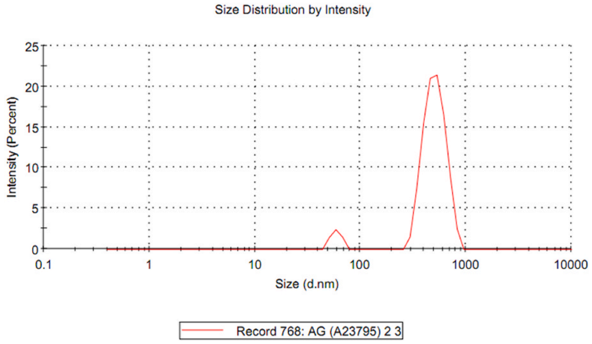

Fig. 5. Size distribution of Ag NPs by DLS method.

accurately. The results in Fig. 6 revealed that the 100 GSM sample exhibited a higher tensile strength of 41.58 N compared to the 26.24 N of the 50 GSM sample. This indicates that the 100 GSM sample is stronger and capable of withstanding greater pulling forces before breaking. Potential reasons for this disparity include variations in manufacturing techniques, resulting in diverse mechanical properties, and differences in fiber structure, encompassing aspects like diameter, density, and molecular arrangement, all impacting the material's resistance to pulling forces [18].

3.5. Air permeability

Fabric air permeability, denoting its ability to allow air passage, is a crucial factor influencing fabric breathability and comfort. Tested at 21 °C, 65 % humidity, and 100 Pa pressure with an area of 20 cm^2, the air permeability values for 12 samples containing xanthan gum, gum Arabic, and silver nanoparticles were examined. In the case of Sample 1 (50 GSM), both front and back sides exhibited similar air permeability values of 483 and 485, respectively, with a minor deviation indicating consistent airflow, as shown in Fig. 7. Conversely, Sample 5 (100 GSM) displayed a notable difference between the front (44.97) and back (52.70) sides, suggesting increased resistance due to the presence of Ag-Bio Polymer. Samples 4 and 11 showcased similar behavior, with slightly lower air permeability values (31.53 for the front side and 33.60 for the back side) and a low standard deviation, indicating a uniform airflow pattern. Due to its less compact shape, the 50 GSM samples allow improved ventilation by providing less resistance to airflow. On the other hand, the increased density of the 100 GSM samples limits air movement and decreases permeability by shrinking the size of the spaces between the fibers. Overall, the results elucidate the air permeability characteristics, showcasing structural and compositional variations and highlighting the impact of increasing Ag-Bio Polymer on decreasing air permeability values (see Fig. 8).

3.6. Wicking test

The ability of fibers to absorb and transport liquid across their surface or through their structure is known as the wicking property. The wicking property of six samples with a weight of 50 GSM was close to 1.3 cm, indicating that the Nanocomposite material on this bandage has a significant capacity to absorb and transmit liquid through capillary action. The composition of hydrogel composite is natural which can easily absorb water while material porosity can facilitate liquid migration could all account for this enhanced wicking property [20]. Six 100 GSM samples had a 0.6 cm decrease in the wicking property due to the bulkier structure of 100 GSM fabric as compared to 50 GSM fabric. The increased weight may have contributed to a more compact structure or reduced porosity, impeding capillary action and consequently limiting the wicking property.

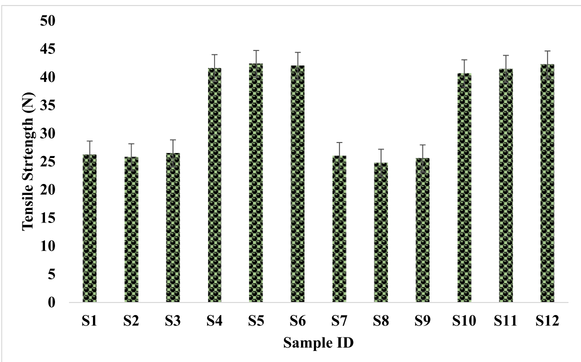

Fig. 6. Tensile Strength of all the samples.

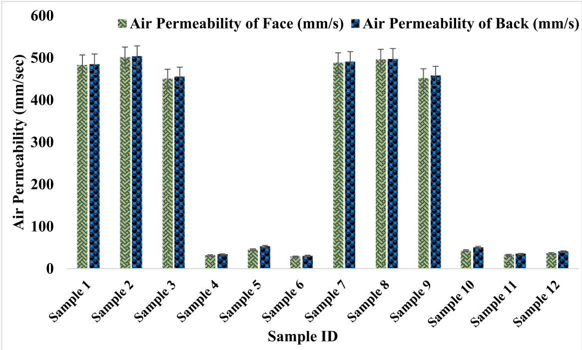

Fig. 7. Air permeability results of the samples.

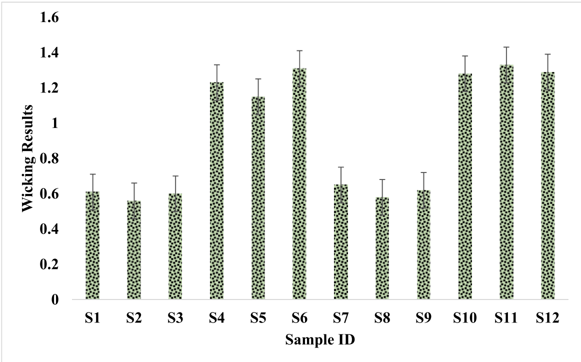

Fig. 8. Wicking Properties of the samples.

3.7. Anti-bacterial characteristics

The antibacterial test results reveal that developed samples' resistance towards the growth of *S. aureus*. Notably, no bacterial growth was observed around the samples, indicating a distinct zone of inhibition and confirming their antibacterial properties.Table 3 presents the zone of inhibition and bacterial growth in each sample.

While all samples demonstrated zero bacterial growth in the contact area, denoting a antibacterial effect, variations in the clear zone of inhibition (mm) offer nuanced insights into the strength of the antibacterial activity, as shown in Fig. 9. A larger clear zone generally signifies a more robust antibacterial effect.

Analyzing each sample individually, Sample 1 exhibited a clear zone of less than 1 mm, indicating a weaker antibacterial activity, possibly limiting effectiveness beyond the immediate contact area. Sample 2 displayed a clear zone of 2.20 mm, suggesting moderate antibacterial activity within a confined area. In contrast, Sample 3, with a clear zone of 2.80 mm, demonstrated slightly stronger antibacterial activity, inhibiting bacterial growth over a larger area. Sample 4 displayed a clear zone of 3.30 mm and sample 5 shows less than 1 mm inhibition zone. Sample 4 stands apart with the most grounded antibacterial movement as compared to other samples, while samples 1 and 5 show nearly more fragile impacts, and samples 2 and 3 present moderate antibacterial action.

4. Conclusion

The study identified the optimal composition of xanthan gum at 0.5 % and gum Arabic at 1 %, resulting in the highest air permeability in the bandage. This suggests that these biopolymers can significantly improve airflow, potentially reducing the risk of skin irritation and promoting faster wound healing. Sample 4 (xanthan: Arabic gum 1:1 with 0.5 % Ag and 100 GSM) demonstrated the most substantial antibacterial effect, indicating potential infection risk reduction when used in wound management. Tensile strength correlated with GSM, emphasizing the importance of material density in bandage durability. The 50 GSM sample outperformed the 100 GSM sample in wicking efficiency, suggesting lower material density could enhance moisture management and wearer comfort. Trade-offs between material density and other properties should be considered for optimal bandage performance. DLS and FTIR analyses provided insights into mechanical performance and chemical composition, contributing valuable knowledge for enhancing medical textile functionality and comfort. Overall, the study offers new insights on the development of Ag-biopolymer blend based cost-effective sustainable cotton bandages that can revolutionize this field. Further research and development are necessary to transition this work from the laboratory to the end consumer.

Table 3
Zone of inhibition and bacterial growth in each sample.

Sample ID	Bacterial Growth in Sample Contact Area	Clear Zone of Inhibition (mm)
S1	No	<1.00
S2	No	2.20
S3	No	2.80
S4	No	3.30
S5	No	<1.00

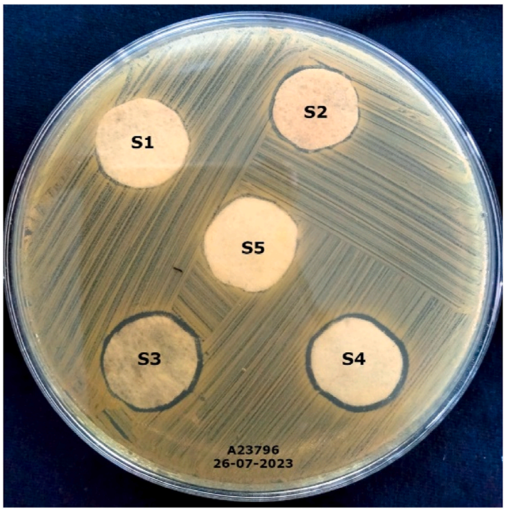

Fig. 9. Antibacterial results of the samples.

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Availability of data and material

The data will be made available as per requirement.

Code availability

Not applicable.

Ethics approval

Not applicable.

Consent to participate

Not applicable.

Consent for publication

Not applicable.

CRediT authorship contribution statement

Muhammad Tauseef: Writing – original draft, Investigation, Conceptualization. **Farooq Azam:** Validation, Software, Methodology, Data curation. **Yasir Iqbal:** Writing – original draft, Investigation, Conceptualization. **Sheraz Ahmad:** Writing – review &

editing, Visualization, Supervision, Resources, Project administration. **Faheem Ahmad:** Supervision, Project administration, Methodology, Data curation. **Rashid Masood:** Project administration, Data curation. **Syed Rashid Habib:** Writing – review & editing, Software, Resources, Funding acquisition, Formal analysis. **Abher Rasheed:** Writing – review & editing, Validation. **Muhammad Sohail Zafar:** Writing – review & editing, Visualization, Funding acquisition, Formal analysis. **Abdul Salam:** Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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