

# Bactericidal Evaluation of Nano-coated Cotton Fabrics

Hanan Basioni Ahmed<sup>1,\*</sup>, Mohammed Hussein El-Rafie<sup>2</sup>, Magdy Kandil Zahran<sup>1</sup>

<sup>1</sup>Chemistry Department, Faculty of Science, Helwan University, Ain-Helwan, Cairo, Egypt

<sup>2</sup>Textile Research Division, National Research Centre, Dokki, Cairo, Egypt

## Email address:

hananbasiony@gmail.com (H. B. Ahmed)

## To cite this article:

Hanan Basioni Ahmed, Mohammed Hussein El-Rafie, Magdy Kandil Zahran. Bactericidal Evaluation of Nano-coated Cotton Fabrics. *American Journal of Nano Research and Applications*. Vol. 3, No. 6, 2015, pp. 105-112. doi: 10.11648/j.nano.20150306.13

**Abstract:** Nano-sized silver particles (AgNPs) were synthesized by easy and quite simple method, using pectin as both reducing and stabilizing agent. Solutions of AgNPs were applied to cotton fabrics in presence/absence of binder. The finished fabrics were examined for morphological and topographical features by using scanning electron microscopy which reveals that AgNPs- pectin composite are deposited on the surface of coated fabrics. Also, color coordinates were measured for the uncoated and coated fabrics to show the effect of nanosilver loading on the color of coated fabrics. The antibacterial activity of the treated fabrics loaded with AgNPs was evaluated against *Escherichia coli*, *Pseudomonas aeruginosa* and *Staphylococcus aureus*.

**Keywords:** AgNPs- Pectin Composite, SEM, Color Coordinates, Bactericidal Activities

## 1. Introduction

In the last two decades, the study and preparation of inorganic crystalline particles in the order of nanometer range has attracted considerable attention of scientists from both fundamental and applied research field [1]. Metal nanoparticles (MNPs), such as silver [2, 3, 4, 6, 7, 8, 9], gold and copper have received special attraction because of their catalytic [12], electronic [13] and unique optical properties [14] making them very attractive in the fields of particularly sensing, bio-conjugation, and surface enhancement Raman spectroscopy (SERS) [15, 16].

Among the noble MNP's, silver has wide recognition for its application in semiconductors [17, 18, 19], superconductors [20, 21], super magnets [22], micro-electronics [23, 24], lithography [16, 25], etc. Recently, researchers have shown that the silver nanoparticles interact with a human immunodeficiency virus and prevent virus from binding to the host cells [26]. The antimicrobial activity of silver nanoparticles is comparatively better than the broad-spectrum most prominent antibiotics used worldwide [27].

Lenard reported that colloidal silver atoms can kill almost any germ which comes in contact with it. Most antibacterial agents available today inactivate or kill only a limited spectrum of bacteria, viruses, or fungi and also these agents often develop the resistance species but silver formulas are exception to this rule [28]. Recently, many studies [7, 39, and 41] reported that, treated cotton fabrics with nanocrystalline

silver particles using pad-dry-cure method. Samples were tested against gram positive and gram negative bacteria for evaluation of the biocidal activities, and they observed that treated fabrics exhibited high levels of bacterial inhibition, while the untreated fabrics did not show any antibacterial activities. More recent researches were interested in manufacturing of multifunctional fabrics by uploading of AgNPs through exploiting fabric backbones with its reducing end groups to play the dual roles of reducer and capping agents for metal nanoparticles [38, 40, and 42].

It is known that the reactivity of polysaccharide molecule is due to terminal sugars, mainly localized in side chains. In addition, conformation features of the macromolecule, caused by intramolecular stabilization bonds between functional groups in side chains, are responsible for biological activity of a polysaccharide.

One of the widespread approaches to the synthesis of metal nanoparticles involves the reduction reaction of metal ions in a polymeric solution [5, 10 and 11]. As a rule, the high-molecular compound (polysaccharide) employed in this case acts as a protective polymeric screen ensuring both the size of metal nanoparticles and stabilization of the nanobiocomposite formed [29, 43]. Borohydrides, aluminium hydrides, aminoboranes, hypophosphites, hydroquinone, formalin, light, and radiation are used in literatures as reducing agents [30].

Pectin is a natural, non-toxic, and amorphous carbohydrate present in cell walls of all plant tissues, which functions as an

intercellular and intracellular cementing material. As a secondary product of fruit juice, sunflower oil, and sugar manufacture industries, pectin is both inexpensive and abundantly available. Therefore, pectin is an excellent candidate for eco-friendly biodegradable applications. Pectin is commonly used in the food industry as a gelling and stabilizing agent. Pectin macromolecules are able to bind with some organic or inorganic substances via molecular interactions. So, pectin can be used to construct matrices to absorb desired materials and deliver them in a controlled manner [31]. Indeed, pectin has been used to fabricate delivery systems for controlled drug release [32], implantable cell carriers [33], and so on.

Currently, hybrid inorganic–organic nanocomposite materials are of great interest because of their multi-functionality owing to a combination of different compounds incorporated [34]. The incorporation of nanocrystalline silver into pectin to form nanocomposite may impart unique functionalities to the nanocomposite prepared, which could be uploaded on the surface of fabrics to be applied in medical purposes.

Herein we report the preparation of pectin–silver nanocomposites [9] to be used for coating cotton fabrics, in order to obtain new product with antimicrobial activities with a facile solution approach. This approach may find potential application in the medical field.

## 2. Experimental

### 2.1. Materials

Silver nitrate ( $\text{AgNO}_3$ , 99.5%), pectin (M.W= 300000 – 1000000) supplied from (Alpha Chemika Company, Mumbai, India), Sodium hydroxide ( $\text{NaOH}$ ), Sodium carbonate monohydrate ( $\text{Na}_2\text{CO}_3 \cdot \text{H}_2\text{O}$ ) and Nitric acid ( $\text{HNO}_3$ , 55%) were all used without further purification. Desized, scoured, and bleached 100% cotton fabrics, were kindly supplied from El-Mahalla Company for Spinning and Weaving, El- Mahalla El-Kubra, Egypt.

### 2.2. Coating Process

Incorporation of silver Nanoparticles in cotton fabrics was performed by pad – dry – cure method. Ag- Cellulosic fabrics was prepared by immersing of fabrics (20 cm × 20 cm) in a colloidal solution bath of silver nanoparticles ( 50 ppm and 100 ppm) for 30 seconds and squeezed to 100% wet pick up using laboratory pad at constant pressure. The samples were dried at 75°C for 15 minutes and cured at 120°C for 3 minutes for thermal fixation of nanoparticles on fabrics surface.

Table 1 shows synthesis process and characterization of AgNPs [9]. 50 and 100 ppm AgNPs colloidal solutions are prepared as follows: 3 g/l pectin was hydrolyzed by 20 g/l  $\text{NaOH}$  at 70°C then  $\text{AgNO}_3$  (0.5 mmole/l in case of preparing 50ppm, and 1mmole/l in case of preparing 100ppm AgNPs) was gradually added, and then left for 30 minutes to complete the preparation process. In case of presence of binder (printo® FX based on acrylate), the binder (10g/l),

was added at the end of preparation process.

## 3. Measurements

### 3.1. UV-Visible Spectroscopy

Silver nanoparticles solutions exhibit an intense absorption peak due to the Surface Plasmon Resonance (SPR). Thus the UV-visible absorption spectra were used to prove the formation of AgNPs colloidal solutions. The UV-visible absorption spectra of AgNPs colloidal solutions were measured using a multi channel spectrophotometer (T80 UV/VIS, d= 10 mm, PG Instruments Ltd, Japan) at wavelengths 250 - 600 nm.

### 3.2. Transmission Electron Microscope (TEM)

For more characterization of the prepared silver nanoparticles, two drops of the silver nanoparticles colloidal solutions were placed on a 400 mesh copper grid coated by carbon film. The morphology and the distribution of AgNPs were characterized by means of a JEOL-JEM-1200 Transmission Electron Microscope.

### 3.3. Particles Size Distribution

The diameter and distribution of silver nanoparticles were calculated by 4 pi analysis software using TEM photos. The average diameter of the silver nanoparticles was determined from the diameter of at least 20 – 100 nanoparticles.

### 3.4. Scanning Electron Microscopy (SEM)

Scanning electron microscopy (SEM) was used to study the surface topographic features of fabrics treated with AgNPs in comparison with the untreated fabrics. Fabric samples were located on copper coated carbon tap double face, and then coated by the gold layer by evaporation of gold in argon atmosphere using sputter coater (S150 A – Edwards, UK). The surfaces of samples were scanned using JEOL X840A – Japan/ JXA – 840A electroprobe Micro Analyzer – Japan.

### 3.5. Moisture Content

Moisture content was measured as follows: 1 g of sample was weighed accurately and then dried at 105°C for 4 h. The dried sample was reweighed; then, moisture content was calculated according to Eq.1, which was found to be 4.54%.

$$\text{MC} = [(A - B)/A] \times 100 \quad (1)$$

Where, MC is moisture content (%), A= initial weight (g) and B= weight of dried fabric (g).

### 3.6. Detection of Silver Content

Silver content in the coated cotton fabrics was measured as follows: 0.2 g of coated dried fabrics was immersed in 30 ml of 15 wt% nitric acid for 2 h at 80°C. Silver concentration was recorded by using flame atomic absorption spectroscopy

(AAS, SpectrAA, 220, Varian, Australian) equipped with silver lamp (328.1 nm). The silver content was calculated by Eq.2.

$$\text{Silver content (mmole/kg)} = \frac{C_s}{W_d/(1 - MC/100)} \times V \quad (2)$$

Where  $C_s$ = silver concentration (mmole/l) in extracted solution which is detected by atomic absorption spectroscopy;  $V$ = volume of extracted solution;  $W_d$ = weight of dried coated fabric (g);  $MC$ = moisture content of coated fabrics (%) [3].

### 3.7. Washings and Silver Release

The washing process of AgNPs coated fabrics can be described briefly as follows (Hossam et al, 2013): treated fabric was immersed in washing solution which contained 2 g/l  $\text{Na}_2\text{CO}_3$  and 2 g/l commercial detergent, using material to liquor ratio 1:50. Then, the samples were stirred and left for 15 minutes at  $55 \pm 5^\circ\text{C}$ . Finally, the fabrics were gently squeezed and rinsed with tap water. This process was repeated 5, 10 and 20 times to get 5, 10 and 20 washings. The silver release was calculated with Eq.3.

$$\text{Silver release (\%)} = [(C_b - C_a) / C_b] \times 100 \quad (3)$$

$C_b$  is the silver content in treated fabrics before washing, and  $C_a$  is the silver content in treated fabrics after washing.  $C_a$  and  $C_b$  were measured by extraction method which is described previously.

### 3.8. Color Measurements

Color measurements of AgNPs coated fabrics were recorded with a colorimeter with pulsed xenon lamps as light source (UltraScan Pro, Hunter Lab, USA). The equipment could be characterized as follows: CIE LAB color space, 10° observer with D65 illuminant, d/2 viewing geometry and measurement area of 2 mm. Color measurement parameters are lightness ( $L^*$ ) from black (0) to white (100),  $a^*$  is a red (+) / green (-) ratio,  $b^*$  is yellow (+) / blue (-) ratio. Each data point was the average of two independent measurements.

### 3.9. Antibacterial Test

The Antimicrobial activity of AgNPs coated cotton fabrics were tested by using two different techniques; qualitative method (inhibition zone technique) and quantitative method (plate count agar method).

The qualitative method was carried out by using a modified Kirby-Bauer disc diffusion technique. Briefly, 100  $\mu\text{l}$  of the tested bacteria were grown in 10 ml of fresh media until they reached a count of approximately 108 cells /ml [35]. A 100  $\mu\text{l}$  of microbial suspension was spread onto agar plates corresponding to the broth in which they were maintained. Plates inoculated separately with Gram (+) bacteria as *Staphylococcus aureus* and Gram (-) bacteria as *Escherichia coli* and *Pseudomonas aeruginosa*, were incubated at 35-37°C for 24-48 hours, then the diameters of the inhibition zones were measured in millimeters. Standard

discs of Tetracycline (Antibacterial agent), served as positive controls for antimicrobial activity, however, filter discs impregnated with 10  $\mu\text{l}$  of solvent (distilled water, chloroform, DMSO) were used as a negative control.

When a part of the AgNPs coated fabrics is placed on agar media, AgNPs will diffuse from fabric into the surrounding. The solubility of nanosilver and its particle size will determine the size of the area of silver infiltration around the fabric. If an organism is placed on agar it will not grow in the area around the fabric (if it is susceptible to the AgNPs). This area of no growth around the coated fabric is known as a "Zone of inhibition" or "Clear zone".

For AgNPs diffusion, the zone diameters were measured with slipping calipers of the National Committee for Clinical Laboratory Standards. The average width for zone of inhibition along a streak on either side of the tested fabric was calculated using eq. 4:

$$W = (T - D) / 2 \quad (4)$$

Where  $W$ =width of clear zone of inhibition in mm,  $T$ = total diameter of tested fabric and clear zone in mm, and  $D$ = diameter of the tested fabric in mm.

The quantitative method was performed for the washed samples against *Staphylococcus aureus* as Gram +ve bacteria according to the AATCC test method 100–1999 for Bacterial Counting. Briefly all treated fabrics were kept at 35°C prior to test. Then, 0.5 g fabrics were transferred into 100 ml of nutrient broth (ca.  $1.5 \times 10^8$  colony forming unit per ml), and shaken vigorously for 1min. A normal saline solution was prepared with 0.9% (w/v), was exposed to serial dilution and then plated onto Mannitol salt agar plates. Plates were incubated at 37°C for 24 hours and then the colonies were counted. The reduction percentage of bacterial colonies was calculated using equation 5.

$$R\% = [(B - A) / B] \times 100 \quad (5)$$

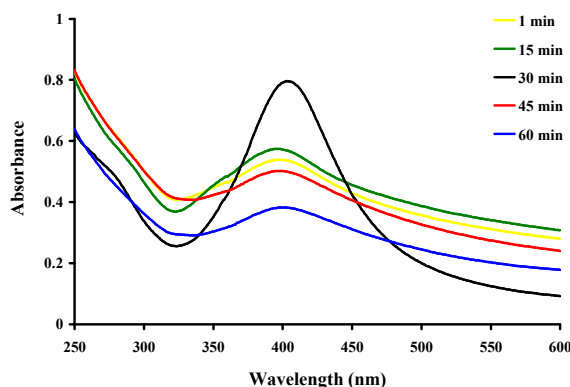
Where  $R\%$  is the reduction percentage of bacterial colonies,  $A$  is the number of bacterial colonies on the agar plate with coated fabric, and  $B$  is the number of bacterial colonies on the agar plate for control.

## 4. Results and Discussion

Nanocomposites synthesis is based on the nanocomposites self-organization, where the polymers play a role of reducing agent and nano stabilizing medium [2, 3, 4, 5, 6, 7, 8, 9, 36]. In this case, synergism of properties of the polymeric matrix (biological activity, hydrodynamical characteristics) and those of the metal core (optical, biological, thermophysical, electric) takes place which provides for promising performance characteristics of the nanocomposites formed. According to this approach, nanobiocomposites have been prepared using natural polysaccharides: arabinogalactan, galactomannan, carboxymethylcellulose, heparin [36], sea seaweed polysaccharides [37], and so forth.

#### 4.1. UV-vis Absorption Spectroscopy

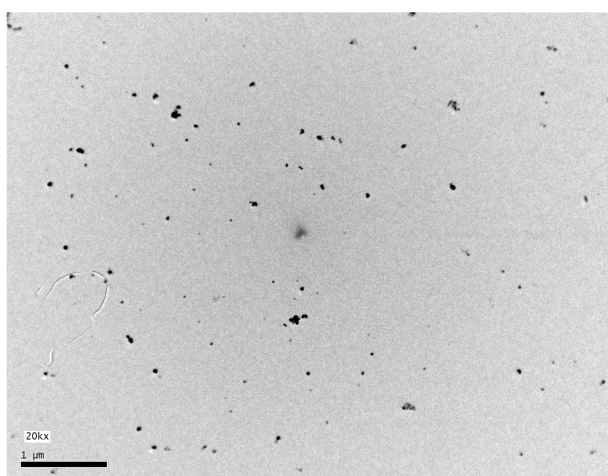
A well-stabilized AgNPs solution with a concentration of 100 ppm was prepared using pectin as reducing agent for silver ions as well as stabilizer for the formed AgNPs in the optimum conditions as follows: pectin, 3g/l g; silver nitrate, 1 mmole/l; pH, 12; temperature, 70°C. Fig.1 shows the UV-vis absorption spectroscopy for AgNPs colloidal solution (concentration of 100 ppm) prepared in the above optimum conditions. It is clear that, the band becomes stronger and more symmetrical with a pronounced bell shape at  $\lambda_{\text{max}}$  409 nm. The band can be assigned to the plasmon resonance of AgNPs.



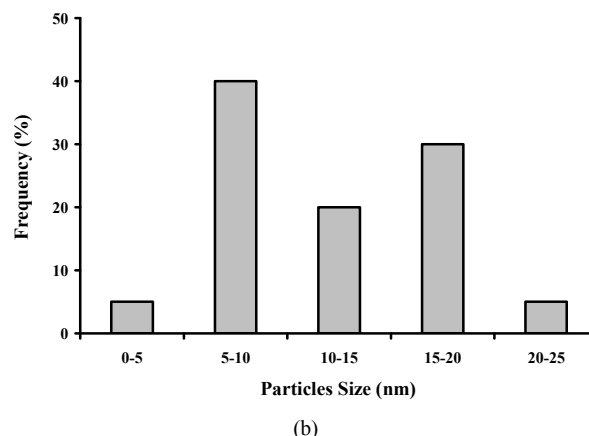
**Figure 1.** UV-Vis absorption spectroscopy of silver nanoparticles (AgNPs) prepared at different durations. Reaction conditions: 3g/l pectin, 1mmole/l AgNO<sub>3</sub>, pH12, temperature 70°C.

#### 4.2. TEM Image and Histogram

Figs.2a&b show the TEM image and the histogram of the size and size distribution of AgNPs in the aforementioned conditions. The obtained figures depict that the resultant product contains a well-stabilized AgNPs solution with a concentration of 100 ppm and a diameter range of (5–10 nm). AgNPs solutions with such unique characteristics are unequivocally feasible for industrial applications. The antibacterial activity of untreated/treated fabrics with colloidal solution of AgNPs is studied, and the obtained data are discussed below.



(a)



**Figure 2.** (a) TEM image silver nanoparticles prepared by 1 mmole/l AgNO<sub>3</sub> (reaction conditions: 3 g/l pectin, pH 12 at 70°C for 30 minute). (b) Size distribution histogram for silver nanoparticles in the viewed TEM image.

#### 4.3. Color Measurements

The CIELAB color system is widely used in the color measurement of textiles. In this system, L\* shows the lightness of the fabric and a\* and b\* indicate red-green (redder if positive; greener if negative) and yellow-blue colors (yellowier if positive; bluer if negative), respectively.

The achieved results are proposed in Table 1 with two concentrations of silver nano particles (50 & 100 ppm), with and without washings. These data showed the effect of pectin – silver nanocomposite on the coated fabric coloration under washing process. Through increasing the amount of the silver nanoparticles on the fabrics from 50 to 100 ppm, b\* values increased and the color of the fabrics tuned to creamy-yellow indicating the formation of the nanoparticles on the fabric surface. In contrast, L\* values are decreased as the lightness of coated fabrics is decreased. However, by washing, b\* values were decreased and L\* values were increased, as the lightness is increased by washing.

By comparing the data measured for the fabric coated with 50 ppm and that were coated with 100 ppm, the difference between L\* values was not significant, which may sign to that 50 ppm is sufficient concentration for the preparation of coated fabric, which could exhibiting antibacterial activities.

**Table 1.** Color coordinates data (CIE lab) for silver-pectin nanocomposite treated fabrics as a function of silver content.

Samples	L*	a*	b*
Blank (Untreated)	93.47 ± 0.15	-0.27 ± 0.08	1.59 ± 0.09
A	1 79.49 ± 1.94	2.23 ± 0.77	11.69 ± 1.55
	2 87.23 ± 0.45	0.15 ± 0.13	2.43 ± 0.18
	3 87.83 ± 0.00	0.08 ± 0.02	2.55 ± 0.06
	4 88.99 ± 0.18	0.01 ± 0.01	2.40 ± 0.16
B	1 75.58 ± 1.26	3.47 ± 0.50	14.21 ± 1.06
	2 84.29 ± 0.08	1.07 ± 0.05	8.38 ± 0.16
	3 85.24 ± 1.56	0.50 ± 0.32	7.09 ± 1.15
	4 85.63 ± 0.23	0.73 ± 0.01	6.30 ± 1.00

A: Cotton treated with 50 ppm AgNPs solution

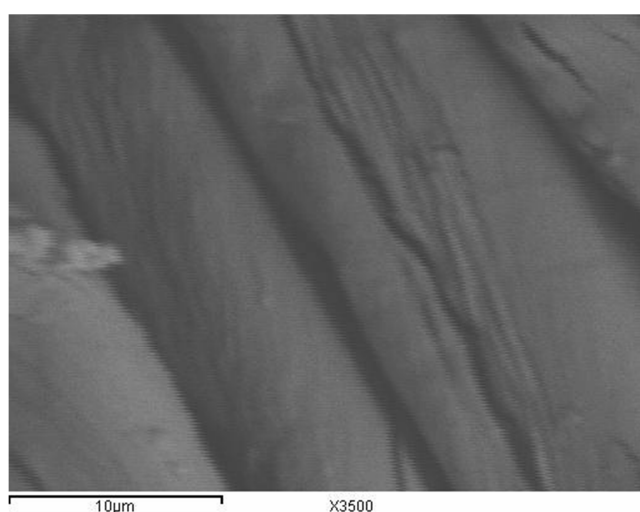
B: Cotton treated with 100 ppm AgNPs solution

1= before washing, 2= after 5 washing cycles

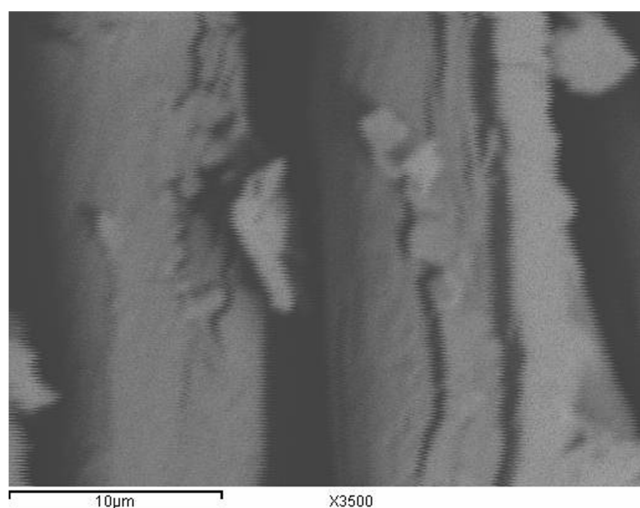
3= after 10 washing cycles and 4= after 20 washing cycles.

#### 4.4. Silver Particle-Coated Fabrics and Surface Characterization (SEM Images)

The surfaces of the nanosilver treated fabrics were examined using SEM images as depicted in Figure 3. Figure 3a showed the surface image of the untreated cotton fabric, while treated fabric with 100 ppm AgNPs colloidal solution in the presence of binder is shown in Figures 3b. It could be observed that, treated fabrics exhibited AgNPs-pectin composite on some concentrated areas of the fabric. It could be supposed that the AgNPs coated on the surface of fabrics could not be seen with SEM, due to their small size and the fact that they are embedded in the polymer matrix of the alkali hydrolyzed pectin, so it could be decided that SEM images reveal aggregates of somewhat larger units of the nanosilver – polysaccharide composite.



(a)



(b)

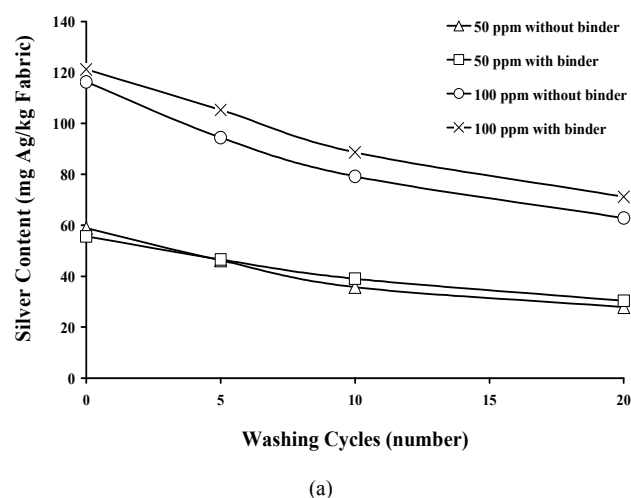
Figure 3. SEM image for (a) untreated cotton fabric and (b) treated fabric.

#### 4.5. Silver Content in AgNPs Coated Cotton Fabrics and Silver Release

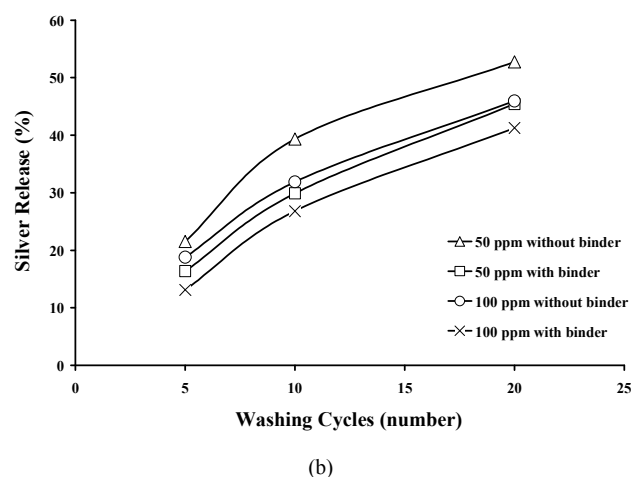
Total silver content in coated fabrics was determined by

atomic absorption spectrophotometer. From Figure 4a, significantly, it could be observed that the actual amount of silver content on the surface of fabrics increased by increasing the concentration of the AgNPs colloidal solution. It could be associated with higher deposition of AgNPs, which is suggested to take a place with fixation therein through physical bonding.

The data also highlighted that, higher concentrations of AgNPs with binder improved nanosilver loading. As by coating fabrics with 100 ppm AgNPs colloids using binder, results in giving the best value of nanosilver loading (121.21mg/kg). This confirms the role of binder in fixation of the deposits of silver nanoparticles within the molecular structure of cotton.



(a)



(b)

Figure 4. (a) Silver contents on the coated fabrics with different treatment conditions with number of washing cycles. (b) Silver release from the coated cotton fabrics in the washing liquor.

To evaluate the laundering durability of nanosilver coated cotton fabrics, Ag content and silver release percent were both measured after different washings. Figure 4b shows the silver release from fabrics after repeated washings. It could be observed that, silver release percent was higher in case of using AgNPs colloidal solution without binder rather than that with binder. As in case of coated fabrics treated with 100

ppm AgNPs in absence of binder, silver release percent was 18.8% after 5 washings, and became 46.0% after 20 washings. However, in the presence of binder, silver release percent was 13.1% after 5 washings, and reached 41.1% after 20 washings. So, it could be summarized that, washing the coated cotton fabrics resulting in removal of nanosilver deposits and this created the idea of incorporating fixing agent in the finishing bath.

#### 4.6. Antimicrobial Assessment of the Silver Coated Fabrics

An antibacterial activity assessment of the fabric samples treated with nanosilver particles was conducted using the method described previously in the experimental part and was compared against untreated fabric. The growth of different bacterial strains directly under the specimens is given in Tables 2 & 3.

When the fabric specimen is placed on top of the bacterial lawn, antimicrobial agents (silver particles) from the fabric diffuse into the media that has bacterial lawn (growth). Untreated cotton specimens showed no antibacterial effect under the sample contact area, where as the unwashed treated fabrics with 50 ppm nanosilver in absence of binder, exhibited considerable antibacterial effect, as the antibacterial activity against *S. aureus*, *E. coli*, and *P. aeruginosa* which was represented in the form of inhibition zone values (mm/1cm fabric) were 2, 2 and 3 mm respectively. However, in the presence of binder, inhibition zone values were 3, 3 and 3 mm respectively.

For treated fabrics with 50 ppm in the presence of binder, washed in 20 cycles, inhibition zone values were 1, 1 and 1.5 mm respectively. For fabric treated with 100ppm nanosilver in the presence of binder and washed by 20 cycles, inhibition zone values for the plates contained the three strains mentioned before were 2, 1 and 2mm respectively.

The bacterial counting method was used as quantitative method for the detection of antibacterial efficacy against *Staphylococcus aureus* as an example of gram positive bacterial species, and data was reported in table 3. The experiment was done only for the coated fabrics subjected to 20 washings. Results of Table 3 also showed that, regardless of the concentration of AgNPs used or silver content of fabrics, the reduction of bacterial colonies was always higher than 80%. An excellent antibacterial property was acquired by the fabrics coated with 100 ppm AgNPs solution in the presence of binder, and subjecting the treated fabrics to washings leads to non sense decrement in the reduction of bacterial colonies, as after 20 washings, fabrics coated with 100 ppm AgNPs colloidal solution (with binder) caused a bacterial reduction reached to 98%. Thus, it still exhibited excellent antibacterial properties.

Thus, it could be concluded that, coating of cotton fabric with 100 ppm AgNPs colloidal solution, in the presence of binder is preferable to obtain excellent antibacterial activity against *S. aureus* as Gram positive bacterial strain and both of *E. coli* and *P. aeruginosa* as Gram negative bacterial strain.

**Table 2.** Effect of washing cycles and silver content on the antibacterial activities of nanosilver coated cotton fabrics against three different bacterial strains.

Samples	Silver content (mg/kg)	Inhibition zone diameter (mm)		
		<i>Staphylococcus aureus</i> (gram +ve)	<i>Escherichia coli</i> (gram -ve)	<i>Pseudomonas aeruginosa</i> (gram -ve)
Blank (Untreated)	0	0	0	0
A	1	58.90	2	3
	2	46.23	1	2
	3	35.73	1.5	1
	4	27.84	1	1
B	1	55.64	3	3
	2	46.53	2.5	2.5
	3	39.00	2	2
	4	30.36	1	1.5
C	1	116.30	3	3.5
	2	94.45	3	2
	3	79.22	2.5	2
	4	62.85	1.5	1.5
D	1	121.21	4	5
	2	105.33	3	3.5
	3	88.70	2	2.5
	4	71.19	2	2

A: Cotton treated with 50 ppm AgNPs solution

B: Cotton treated with 50 ppm AgNPs solution in presence of binder

C: Cotton treated with 100 ppm AgNPs solution

D: Cotton treated with 100 ppm AgNPs solution in presence of binder

1= before washing, 2= after 5 washing cycles

3= after 10 washing cycles and 4= after 20 washing cycles.

**Table 3.** Quantitative analysis of antibacterial activities for AgNPs treated cotton fabrics after 20 washing cycles.

Samples	Silver content (mg/kg)	Bacterial reduction (%)
		<i>Staphylococcus aureus</i> (gram +ve)
Blank (Untreated)	0	0
A	27.84	82
B	30.36	84
C	62.85	94
D	71.19	98

A: Cotton treated with 50 ppm AgNPs solution

B: Cotton treated with 50 ppm AgNPs solution in presence of binder

C: Cotton treated with 100 ppm AgNPs solution

D: Cotton treated with 100 ppm AgNPs solution in presence of binder

## 5. Conclusion

We developed a simple approach to prepare pectin–silver nanocomposite in aqueous alkaline solution. The experimental results confirm the true pectin–nanosilver composite structure and the existence of strong interaction between pectin molecules and silver, and its stabilized physical deposition on the surface of coated fabrics. As, the obtained AgNPs were successfully applied to cotton fabrics, and it is found that, using 100 ppm of AgNPs with binder showed excellent antibacterial activity against *E. coli*, *P.*



*aeruginosa* and *S. aureus*. The SEM analysis indicates that the AgNPs are well dispersed on the cotton fabrics. Binder was used successfully in this work to diminish the bacterial growth on the coated cotton fabrics. The result of durability to wash of the coated fabric also showed long-lasting bactericidal effect even after 20 washing cycles. Therefore, this kind of treatment could be expressed as a safe, cost effective and environmental friendly process, easily applicable for antibacterial finishing, and may be extended to prepare other hybrid inorganic–organic nanocomposite materials.

## References

- [1] Elghanian, R., Storhoff, J. J., Mucic, R. C., Letsinger, R. L., & Mirkin, C. A. (1997). Selective colorimetric detection of polynucleotides based on the distance-dependent optical properties of gold nanoparticles. *Science*, 277, 1078–1081.
- [2] Emam, H. E., Mowafi, S., Mashaly, H. M., Rehan, M. (2014). Production of Antibacterial Colored Viscose Fibers Using In-Situ Prepared Spherical Ag nanoparticles. *Carbohydrate Polymers*, doi.10.1016/j.carbpol.2014.03.082.
- [3] Hossam E. E., Avinash P. M., Barbora S., Heinz D., Bernhard R., Alexandra P., Thomas B. (2013). Treatments to impart antimicrobial activity to clothing and household cellulosic-textiles e why “Nano”-silver? *Journal of Cleaner Production*, 39, 17-23.
- [4] Hebeish, A. A., El-Rafie, M. H., Abdel-Mohdy, F. A., Abdel-Halim, E. S., Emam, H. E., (2010). Carboxymethyl cellulose for green synthesis and stabilization of silver nanoparticles. *Carbohydrate Polymers*, 82, 933–941.
- [5] 7. M. H. El-Rafie, Hanan B. Ahmed, M. K. Zahran. (2014). Facile precursor for synthesis of silver nanoparticles using alkali treated maize starch. *International Scholarly Research Notices*, Volume 2014, Article ID 702396, 12 pages.
- [6] El-Rafie, M. H., Hanan B. Ahmed, Zahran, M. K. (2014). Characterization of nanosilver coated cotton fabrics and evaluation of its antibacterial efficacy. *Carbohydrate polymers*, 107, 174-181.
- [7] Zahran, M. K., Hanan B. Ahmed, El-Rafie, M. H. (2014a). Surface modification of cotton fabrics for antibacterial application by coating with AgNPs-Alginate composite. *Carbohydrate polymers*, 108, 145-152.
- [8] Zahran, M. K., Hanan B. Ahmed, El-Rafie, M. H. (2014b). Alginate mediate for synthesis controllable sized AgNPs. *Carbohydrate polymers*, IN PRESS.
- [9] Zahran, M. K., Hanan B. Ahmed, El-Rafie, M. H. (2014c). Facile size regulated synthesis of silver nanoparticles using pectin. *Carbohydrate polymers*, 111, 971–978.
- [10] Hossam E. Emam, Avinash P. Manian, Barbora Široká, Heinz Duelli, Petra Merschak, Bernhard Redl, Thomas Bechtold. 2014. Copper (I) oxide surface modified cellulose fibers—Synthesis, characterization and antimicrobial properties", *Surface and Coatings Technology*, 254, 344–351.
- [11] Hossam E. Emam, Manal K. El-Bisi. (2014). Merely Ag nanoparticles using different cellulose fibers as removable reductant. *Cellulose*, 21, 4219–4230.
- [12] Mallik, K., Witcomb, M. J., & Scurell, M. S. (2005). Redox catalytic property of gold nanoclusters: Evidence of an electron-relay effect. *Applied Physics A*, 80, 4, 797–801.
- [13] Kamat, P. V. (2002). Photophysical, photochemical and photocatalytic aspects of metal nanoparticles. *Journal of Physical Chemistry B*, 106, 7729–7744.
- [14] Liz-Marzan, L. (2006). Tailoring surface plasmons through the morphology and assembly of metal nanoparticles. *Langmuir*, 22, 32–41.
- [15] Cao, Y. C., Jin, R., Nam, J., Thaxton, C. S., & Mirkin, C. A. (2003). Raman-dye-labeled nanoparticle probes for proteins. *Journal of American Chemical Society*, 125, 14676–14677.
- [16] Shipway, A. N., Lahav, M., & Willner, I. (2000). Nanostructured gold colloid electrodes. *Advanced Materials*, 12, 13, 993–998.
- [17] Henglein, A. (1989). Small-particle research: Physicochemical properties of extremely small colloidal metal and semiconductor particles. *Chemical Review*, 89, 1861–1873.
- [18] Kamat, P. V. (1993). Photochemistry on nonreactive and reactive (semiconductor) surfaces. *Chemical Reviews*, 93, 267–300.
- [19] Schmid, G. (1992). Large clusters and colloids metals in the embryonic state. *Chemical Reviews*, 92, 1709–1727.
- [20] Henglein, A. (1993). Physicochemical properties of small metal particles in solution: Microelectrode reactions, chemisorption, composite metal particles, and the atom-to-metal transition. *Journal of Physical Chemistry*, 97, 5457–5471.
- [21] Pileni, M. P. (1993). Reverse micelles as microreactors. *Journal of Physical Chemistry*, 97, 6961–6973.
- [22] Lee, A. F., Baddeley, C. J., Hardacre, C., Ormerod, R. M., Lambert, R. M., Schmid, G., et al. (1995). Structural and catalytic properties of novel Au/Pd bimetallic colloid particles: EXAFS, XRD and acetylene coupling. *Journal of Physical Chemistry*, 99, 6096–6102.
- [23] Deheer, W. A. (1993). The physics of simple metal clusters; experimental aspects and simple models. *Reviews of Modern Physics*, 65, 611–676.
- [24] Littau, K. A., Szajowski, P. J., Muller, A. J., Kortan, A. R., & Brus, L. E. (1993). A luminescent silicon nanocrystal colloid via a high-temperature aerosol reaction. *Journal of Physical Chemistry*, 97, 1224–1230.
- [25] Xia, A., Rogers, J. A., Paul, K. E., & Whitesides, G. M. (1999). Unconventional methods for fabricating and patterning nanostructures. *Chemical Reviews*, 99(7), 1823–1848.
- [26] Elechiguerra, J. L., Burt, J. L., Morons, J. R., Camachobragado, A., Gao, X., Lara, H. H., et al. (2005). Interaction of nanoparticles with HIV-1. *Nanobiotechnology*, 3, 6–16.
- [27] Roy, R., Hoover, M. R., Bhalla, A. S., Slaweeckl, T., Dey, S., Cao, W. (2008). Ultradilute Ag-aquasols with extraordinary bactericidal properties; role of the system Ag–O–H<sub>2</sub>O. *Materials Research Innovations*, 11, 3–18.
- [28] Lenard, L. (2009). Silver-protein: Gold standard among antimicrobial agents, [http://intelegence.com/ImmuneSystem/silver\\_protein.htm](http://intelegence.com/ImmuneSystem/silver_protein.htm).

- [29] Litmanovich, O. E. (2008) "Pseudomatrix sintez of polymer-metal nanocomposite sols: interaction of macromolecules with metal nanoparticles. Chinese Journal of Polymer Science C, 58, 7, 1370–1396.
- [30] Pomogailo, A.D. (1997). Polymer-immobilised nanoscale and cluster metal particles, *Uspekhi Khimii*, 66, 8, 785–791.
- [31] Liu L. S., Cooke P. H., Coffin D. R., Fishman M. L., Hicks K. B. (2004). Pectin and polyacrylamide composite hydrogels: effect of pectin on structural and dynamic mechanical properties. *Journal of Applied Polymer Science*, 92, 1893–1901.
- [32] Vandamme, T.F., Lenourry, A., Charrueau, C., Chaumeil, J.C. (2001). The use of polysaccharides to target drugs to the colon. *Carbohydrate Polymers*. 48, 219.
- [33] Liu, L., Fishman, M., Kost, J., Hicks, K.B. (2003). Pectin-based systems for colon-specific drug delivery via oral route. *Biomaterials*, 24, 3333–3343.
- [34] Yao, K. X.; Zeng, H. C. (2007). ZnO/PVP nanocomposite spheres with two hemispheres. *Journal of physical chemistry. C*, 111, (36), 13301-13308.
- [35] Pfaller, M., Burmeister, L., Bartlett, M., Rinaldi, M., (1988). Multicenter evaluation of four methods of yeast inoculum preparation. *Journal of Clinical Microbiology*, 26, 1437–1441.
- [36] Trofimov, B. A., Sukhov, B. G., Aleksandrova G. P. (2003). Nanocomposites with magnetic, optical, catalytic, and biologically active properties based on arabinogalactan. *Doklady Chemistry*, 393, 287–288.
- [37] Yurkova, I. N., Panov, D. A., Ryabushko, V. A. (2009). Study of optical properties of nanobiocomposites on silver and marine alga polysaccharides base. *Uchenye Zapiski Tavricheskogo Universiteta Series Biologiya and Khimiya*, 22, 1, 203–207.
- [38] Mohamed Rehan, Hamada M. Mashaly, Salwa Mowafi, A. Abou El-Kheir, Hossam E. Emam. (2015). Multi-functional textile design using in-situ Ag NPs incorporation into natural fabric matrix. *Dyes and Pigments* 118, 9-17.
- [39] Hossam E. Emam, M. K. Zahran. (2015). Ag<sup>0</sup> nanoparticles containing cotton fabric: synthesis, characterization, color data and antibacterial action. *International Journal of Biological Macromolecules*, 75, 106 – 114.
- [40] Hossam E. Emam, N.H. Saleh, Khaled S. Nagy, M.K. Zahran. (2015) Functionalization of medical cotton by direct incorporation of silver nanoparticles", *International Journal of Biological Macromolecules*, 78, 249–256.
- [41] Hossam E. Emam, M. H. El-Rafie, Hanan B. Ahmed, M. K. Zahran. (2015). Room Temperature Synthesis of Metallic Nanosilver Using Acacia to Impart Durable Biocidal Effect on Cotton Fabrics", *Fibers and Polymers*, 16(8), 1676 – 1687.
- [42] Hossam E. Emam, Thomas Bechtold. (2015). Cotton fabrics with UV blocking properties through metal salts deposition. *Applied Surface Science*, <http://dx.doi.org/10.1016/j.apsusc.2015.09.095>.
- [43] Hossam E. Emam, Hanan B. Ahmed. (2016). Review: Polysaccharides templates for assembly of nanosilver", *Carbohydrate Polymers*, 135, 300 – 307.