Cellulose (2018) 25:5443–5454
https://doi.org/10.1007/s10570-018-1953-6

ORIGINAL PAPER

Study on antibacterial finishing of cotton fabric with silver nanoparticles stabilized by nanoliposomes

Jidong Ru · Xueren Qian · Ying Wang

Received: 7 May 2018 / Accepted: 17 July 2018 / Published online: 19 July 2018
© Springer Nature B.V. 2018

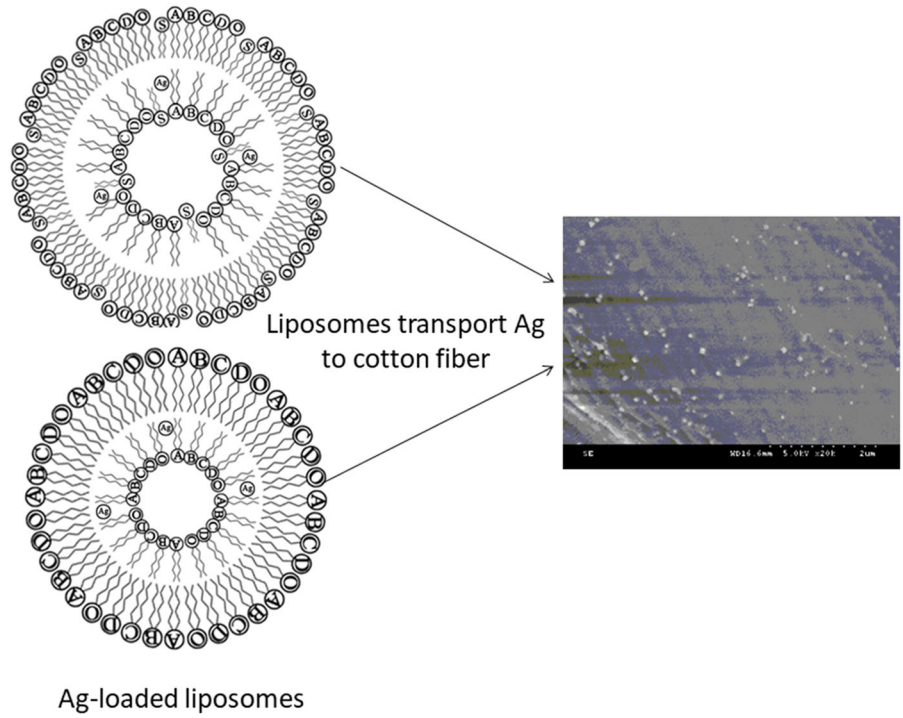
Abstract The main objective of this investigation was to improve the dispersion effect of silver nanoparticles on nano silver sol preparation by encapsulation of silver nanoparticles in neutral nanoliposomes (NL) and cationic nanoliposomes (CL) as an alternative to polyvinylpyrrolidone (PVP). Prepared Ag-liposome nanocomposites and antibacterial cotton fabrics were characterized by XRD, TEM, SEM and XPS respectively. The sterilizing rate and nano silver content of CL were better compared with NL due to the positive charge of CL. The whiteness of antibacterial cotton fabrics using NL and CL as stabilizer was obviously higher than that of one using PVP as stabilizer. The cotton fabrics finished with the silver nanoparticles stabilized by PVP, NL and CL all showed a good antibacterial activity against *Staphylococcus aureus* and *Escherichia coli*, and the sterilizing rates all were above 99.34%. Furthermore, sterilizing rates of cotton fabrics using three different stabilizers still could meet the requirements of antibacterial textile after 10 and 50 times standard washing. These results indicated the potential of nanoliposomes, especially CL, as a novel stabilizer for nano silver antibacterial application.

J. Ru
College of Light Industry and Textile, Qiqihar University, Qiqihar 161006, Heilongjiang Province, China
e-mail: rujidong@126.com

J. Ru · X. Qian (✉)
Key Laboratory of Bio-based Material Science and Technology of Ministry of Education, Northeast Forestry University, Harbin 150040, Heilongjiang Province, China
e-mail: qianxueren@aliyun.com

Y. Wang
College of Computer and Control Engineering, Qiqihar University, Qiqihar 161006, Heilongjiang Province, China
e-mail: wangying0129@126.com

Graphical abstract



Keywords Cotton fabric · Silver nanoparticles · Antibacterial finishing · Nanoliposomes · Stabilizer

Introduction

Silver owing to its unique optical, magnetic, catalytic and antibacterial properties has been applied in various materials, such as cryogenic superconducting (Jiang et al. 2004), antibacterial (Hirano et al. 2003), and biosensor (Ren 2002) materials. Using Ag as antibacterial agent is the most important application of silver ions in the textile field (Ki et al. 2007). Silver salts have prominent antimicrobial effect, and are used to control bacterial growth in a variety of medical applications, including dental work, catheters, and the healing of burn wounds (Crabtree et al. 2003; Singh et al. 2017). It is well known that silver ions and silver-based compounds are highly toxic to microorganisms and exhibit strong bactericidal effect on twelve species of bacteria, including *Escherichia coli* (Singh et al. 2017).

Generally, silver-based antibacterial agents can be divided into the following four categories: colloidal silver, inorganic silver salt, silver sulfadiazine and nano silver (Chen et al. 2017). At present, nano silver has become one of the most important antibacterial agents for textiles with the rapid development of nanotechnology. Nanoparticles are usually aggregates formed from several to dozens of atoms and range from 1 to 100 nm (Dzenis 2004). Nanoparticles show novel properties owing to their small size, which largely differ from the bulk materials (Zhang and Webster 2009). Nano silver like other nanoparticles also usually shows surface effect, small size effect and macroscopic quantum tunneling effect etc. (Morones et al. 2005). Compared with other silver-based antibacterial agents, only infinitesimal nano silver has very strong bactericidal ability (Sheng and Yang 2017). In addition, nano silver also has the advantages of lasting antibacterial, good permeability, safety to human body and good stability to heat and light etc. (Guo et al. 2017).

Many methods have been employed to synthesize nano silver. The chemical reduction method owing to its simple operation and mild reaction conditions has

been extensively studied in the synthesis of nano silver (Chen et al. 2017). $AgNO_3$ as a precursor of Ag^0, reducing agent and stabilizer are usually used in the preparation of silver nanoparticles (Salaheldin et al. 2017). The formation mechanism of nano silver colloids has been demonstrated, and the stronger the reductant, the smaller the silver nanoparticles (Rafique et al. 2016). Nano silver colloids are formed from silver ions in solution through nucleation, followed by the growth step (Parham et al. 2017). The synthesized silver nanoparticles are unstable and rapidly undergo agglomeration owing to their high reactivity (Abbasi et al. 2014). The antibacterial activity of the aggregated silver nanoparticles will be weakened even disappeared. Stabilizers are used to separate silver nanoparticles to prevent them from agglomeration (Arokiyaraj et al. 2017). The surfactants or polymers, such as polyvinylpyrrolidone (PVP), are usually used as stabilizers to control the size of silver nanoparticles (Ali et al. 2017). In addition, liposome was also used as silver nanoparticles stabilizer to enhance the biocompatibility of synthesized silver nanoparticles for drug delivery (Bothun 2008).

Liposome (also called lipid globule) is an amphoteric compound containing both hydrophobic and hydrophilic parts (Neves et al. 2016). Liposomes or phospholipids vesicles are the assembling structures formed by surface-active biological lipids that arrange themselves by exposing their hydrophilic polar head parts toward the aqueous phase and nonpolar hydrophobic hydrocarbon tails that adhere together in the bilayer. They form closed vesicles with a water core and an internal water domain that is trapped between the lipid bilayers. Liposomes have the ability to encapsulate a variety of hydrophobic and hydrophilic solutes and slowly release them (Daraee et al. 2014; Shaker et al. 2017). In liposomes, encapsulated solutes can be achieved by trapping solutes within the water vesicle core or within the hydrophobic lipid bilayer. Silver nanoparticles can be entrapped in the hydrophobic lipid bilayer structure (Bothun 2008; Morones et al. 2005). Liposomes are nontoxic, harmless, as well as biodegradable.

In textiles, liposomes have been examined as a mean of delivering dyestuffs to fibers in a cost-effective and environmentally sensitive manner (Baptista et al. 2003a). Liposomes as vehicle in wool dyeing with acid dyes, disperse dyes and metal complex dyes were investigated, and the dyeing of wool and wool blends with liposomes showed better quality, energy saving, and lower environmental impacts (Baptista et al. 2003b; El-Zawahry et al. 2007; Marti et al. 2001). Compared with traditional retarding agents, liposomes can slowly release the microencapsulated dye to increase the retarding effect, are a good alternative to commercial leveling agents (Marti et al. 2001). Marti et al. used an optimized mixture of commercial liposomes and cationic surfactant to improve leveling effect, the presence of 1% liposomes during exhaustion at 85 °C improved the leveling effect of Irgalan Blue FBL, and the fastness properties of the dyed fibers with liposomes were also been improved (Martí et al. 2007). The research results from Sheveleva et al. showed that liposomes may be employed in the preparation of textile materials (Telegin et al. 2013).

In this study, neutral nanoliposomes (abbreviated as NL) and cationic nanoliposomes (abbreviated as CL) were applied to nano silver antibacterial finish of cotton fabric as novel stabilizer to enhance the stability effect of silver nanoparticles on cotton fabric as an alternative to PVP. The morphology, particle size and zeta potential of CL and NL were studied, the antibacterial effects of three kinds of stabilizers (CL, NL and PVP) were investigated, and the stability mechanisms of PVP, NL and CL on silver nanoparticles were analyzed. Prepared Ag-liposome nanocomposites and antibacterial cotton fabrics were characterized by XRD, TEM, SEM and XPS, respectively.

Materials and methods

Materials

Commercial soybean lecithin, comprised 28 mol% phosphatidylcholine, 16 mol% phosphatidylethanolamine, 14 mol% phosphatidylinositol, and 4 mol% phosphatidic acid as the main ingredients, was provided by Merya's Lecithin Co., Ltd. (Beijing, China). Stearamide was purchased from Sigma Chemical Co. (St. Louis, MO, USA). Bleached cotton fabric (32 cm × 68 cm) was obtained from Keshan Jinding Linen Textile Co., Ltd. (Qiqihar, China). Silver nitrate was purchased from Tianjin Kemiou Chemical Reagent Co., Ltd. (Tianjin, China). Polyvinylpyrrolidone (PVP) and polyethylene glycol (PEG 600) were

supplied by Tianjin Guangfu Fine Chemical Research Institute (Tianjin, China). Powdered agar and peptone were obtained from Hangzhou Baisi Biotechnology Co., Ltd. (Hangzhou, China). Extractum carnis was purchased from Beijing Shuangxuan Microbe Culture Medium Products Factory (Beijing, China). *Escherichia coli* ATCC8099 and *Staphylococcus aureus* ATCC6358 were supplied by College of Food and Biological Engineering, Qiqihar University. Other all reagents were analytically pure and used as received.

Preparation of NL and CL

NL and CL were prepared according to the thin-film hydration method. Commercial soybean lecithin was first purified at 36 °C for 20 min under 25 MPa by a supercritical carbon dioxide extractor (Hua'an Supercritical Fluid Extraction Co., Ltd., China). Purified soybean lecithin (or purified soybean lecithin and stearamide) were entirely dissolved in chloroform to achieve a homogenous mixture of lipids, and then were sonicated at 25 °C for 5 min. Chloroform was entirely distilled by rotary evaporation at 40 °C to obtain a thin lipid film formed on the sides of a round bottom flask. The thin lipid film was dried under vacuum overnight to completely remove residual organic solvent (Ahani et al. 2017; Aisha et al. 2014). Hydration of the dry thin lipid film was accomplished simply by adding deionized water to the round bottom flask under high speed agitation. Prepared NL and CL emulsion again were sonicated at 25 °C for 5 min. Finally, prepared NL and CL emulsion were treated 5 times under 60 MPa through a high pressure homogenizer (Shanghai Precise Machinery Equipment Co., Ltd., China) (Visht et al. 2014).

Synthesis of Ag-liposome Nanocomposites

The synthesis of Ag-liposome nanocomposites was carried out in a nanoliposomes structure by a simplified operational procedure. Ag-liposome nanocomposites were synthesized by adding a prepared nanoliposomes solution to an excess reducing agent (PEG 600) solution under stirring at room temperature. Next, the precursor ($AgNO_3$) solution was added dropwise to the above prepared mixed solution of nanoliposomes and PEG under stirring at room temperature. The $AgNO_3$ solution was thoroughly reduced and formed monodispersed silver nanoparticles when a clear yellow colloidal solution was obtained. Finally, the prepared Ag-liposome colloidal solution was sonicated at 25 °C for 10 min to transform the large nanoparticles into small ones.

Antibacterial finishing of cotton fabric

Antibacterial finishing of cotton fabric was implemented by impregnation and oven-drying method. Namely, 6 g bleached cotton fabric was impregnated in a prepared 0.2 mol/L Ag-liposome colloidal solution with a liquor ratio of 1:30 at 80 °C for 40 min, and then was oven-dried at 85 °C for 3 min.

Analysis and testing

Morphology

The morphology of Ag-liposome nanocomposites, NL and CL were obtained using an H-7650 transmission electron microscope (Hitachi, Japan). After colloidal solution of Ag-liposome nanocomposites, NL and CL were properly diluted, they were dripped on the special copper mesh covered with carbon film, then negatively stained with 20 g/L phosphotungstic acid solution. Morphologies and sizes of Ag-liposome nanocomposites, NL and CL were observed and recorded.

Zeta potential and particle size

NL and CL colloidal solutions were first diluted to 1.5 mL with phosphate buffer solution (pH 7.6), then the zeta potentials and particle sizes of NL and CL were measured using a Zetasizer Nano ZS90 (Malvern Instrument, UK).

XRD characterization

The prepared colloidal solution of Ag-liposome nanocomposites was dried, and analyzed using a D8 X-ray diffractometer (BRUKER-AXS, Germany). Scanning angle 2θ was 30–80°, scanning speed was 2°/min. Finally, the curve of X-ray diffraction intensity (I) versus 2θ (i.e., I–2θ curve) was obtained.

SEM observation of cotton fabric

Surface morphologies of non-antibacterial and antibacterial cotton fabrics were observed using a S-3400 scanning electron microscope (Hitachi, Japan), and acceleration voltage was 5 kV. The sample was coated with gold before observation.

Determination of nano silver content

The antibacterial cotton fabric was equally divided into two pieces and weighed separately, and then two parallel experiments were done. The cloth sample was first digested separately with concentrated nitric acid, and then the volume was fixed to 100 mL with dilute nitric acid, and finally, the content of nano silver was measured using a 7500 Ce inductively coupled plasma mass spectrometer (Agilent Technologies Inc., America).

Qualitative analysis of elements

Elements of antibacterial cotton fabric were qualitatively analyzed using an ESCALAB250Xi XPS photoelectron spectrometer (Thermo Fisher, America), and hemispherical analyzer energy scan range was 0–5000 eV.

Testing

Whiteness of cotton fabric was measured by a YQ-Z-48A brightness color tester (Hangzhou Qingtong Boke Automation Technology Co., Ltd., China). Standard washing of antibacterial cotton fabric was implemented according to the simplified procedure of Appendix C of FZ/T73023-2006 Antibacterial Knitwear. The sterilizing rate of antibacterial cotton fabric was determined according to the oscillation method of Appendix D of FZ/T73023-2006 Antibacterial Knitwear.

Results and discussion

NL and CL characterization

NL and CL colloidal solutions were first prepared and characterized at the beginning of this work. The transmission electron microscope (TEM) images of NL and CL colloidal solutions are shown in Fig. 1. NL and CL nanoparticles were basically spherical, and they were very uniform in size. Owing to the addition of stearamide, the size of CL (around 30 nm) was obviously larger than that of NL (around 20 nm). The dispersity of CL also was better than that of NL due to the coulomb repulsion between CL.

The particle sizes and zeta potentials of NL and CL were determined by Zetasizer Nano ZS90, the results are listed in Table 1. The average particle size of NL was 30.47 nm, whereas the average particle size of CL was 41.71 nm due to the addition of stearamide. The inconsistence of the NL and CL particle sizes from Fig. 1 and Table 1 might be caused by the difference in the measuring principle of the two kinds of instruments. The particle sizes from Table 1 were the mean values of the all NL and CL nanoparticles, while these from Fig. 1 were the estimated values of some NL and CL nanoparticles. We think NL and CL nanoparticles sizes in Table 1 were more accurate. As can also be seen from Table 1, NL was electrically almost neutral (− 1.69 mV), yet CL was obviously positive (+ 27.8 mV), which could be due to the addition of stearamide. The zeta potentials of nano Ag without stabilizer and PVP are 3.31 and − 2.24 mV, respectively. Because the zeta potential of cotton is negative, positive stabilizer would benefit to the adsorption of nano silver on the surface of cotton fabric.

XRD analysis of silver nanoparticles

The prepared silver nanoparticles were characterized by X-ray diffraction, XRD spectrum is shown in Fig. 2. There were four strong diffraction peaks at 2θ values of 38.18°, 44.28°, 64.54° and 77.38°. The above four diffraction peaks corresponded to the 111, 200, 220 and 311 crystal planes of silver nanoparticles, respectively, which were in excellent agreement with JCPDS card No. 4-0783. This indicated that the prepared nano silver was elemental silver.

Dispersion stability of Ag-liposome nanocomposites

Four kinds of prepared nano-silver sols were placed for 24 h, the placed nano-silver sols were observed using transmission electron microscope (TEM), and the results are shown in Fig. 3. It can be seen that the

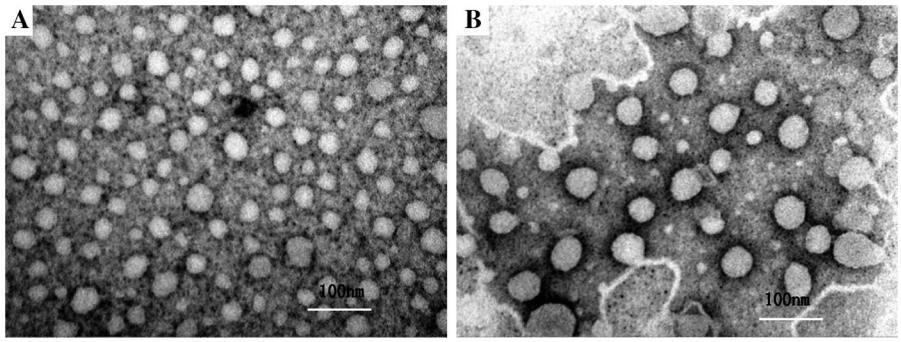


Fig. 1 TEM images of NL (**a**) and CL (**b**)

Table 1 Particle sizes and zeta potentials of NL and CL

Liposome type	Particle size (nm)	Zeta potential (mV)	Zeta deviation (mV)
NL	30.47	− 1.69	8.04
CL	41.71	+ 27.8	5.62

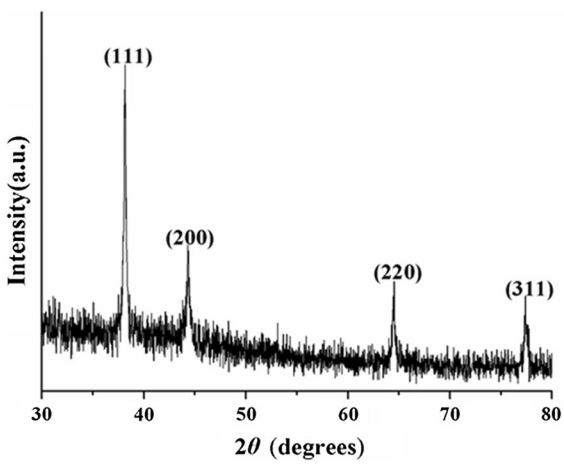


Fig. 2 XRD curve of silver nanoparticles

dispersion stability of nano-silver sol without any stabilizer was very poor, and serious agglomeration occurred (Fig. 3a). As observed from Fig. 3b and c, the dispersion stabilities of nano-silver sols with NL and CL stabilizer were very good, most Ag nanoparticles had been encapsulated by nanoliposomes, the amounts of the unencapsulated Ag nanoparticles in solution were relatively small and the probability of Ag nanoparticles collision was also very low. Therefore, these unencapsulated Ag nanoparticles in solution also didn't agglomerate together. As shown in Fig. 3d, the prepared Ag nanoparticles were uniformly adsorbed on polymeric membrane formed by PVP, and the desired dispersion effect also had been achieved although the stability mechanism of PVP was different from that of NL and CL.

PVP, NL and CL mediated antibacterial finishing of cotton fabric

Cotton fabric was antibacterially finished with three kinds of nano silver sols prepared with PVP, NL and CL as stabilizer, respectively, and the indexes of antibacterial cotton fabrics are shown in Table 2. The indexes obtained indicated that nanoliposomes, especially CL, had remarkable antibacterial effect on cotton fabric in comparison with traditional stabilizer PVP. The sterilizing rate and nano silver content of antibacterial cotton fabric finished by using CL as stabilizer were better than those of antibacterial cotton fabric finished by using NL as stabilizer, which may be because CL has a positive charge, while cellulose fibers are negatively charged in water, so more silver nanoparticles encapsulated by CL can be adsorbed on the surface of cellulose fibers more quickly compared with NL. The whiteness of antibacterial cotton fabrics using NL and CL as stabilizer were obviously higher than that of one using PVP as stabilizer, although the contents of nano silver on cotton fabrics were not different. The main reason for this phenomenon was

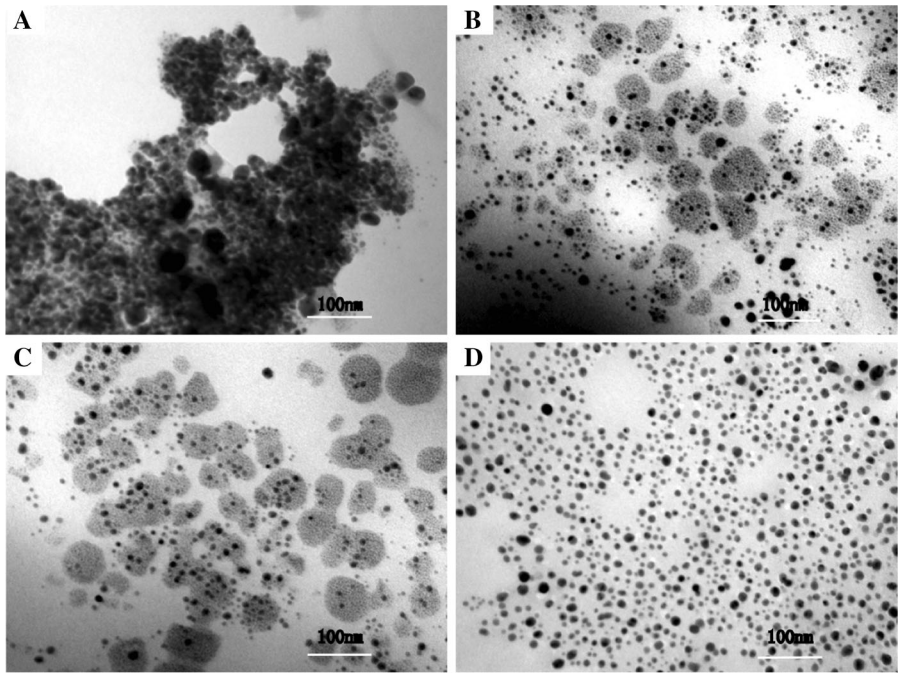


Fig. 3 TEM images of nano silver sols placed for 24 h. **a** Without stabilizer, **b** NL as stabilizer, **c** CL as stabilizer, and **d** PVP as stabilizer

Table 2 Indexes of antibacterial cotton fabrics finished with three different stabilizers

Index	Unfinished	PVP	NL	CL
S. aureus colony number	2,280,000	11,300	13,800	12,900
Sterilizing rate against *S. aureus* (%)	0	99.50	99.39	99.43
E. coli colony number	2,470,000	12,500	16,400	14,700
Sterilizing rate against *E. coli* (%)	0	99.49	99.34	99.40
Content of nano silver on cotton fabric (mg/g)	0	95.8	92.1	96.6
Whiteness of cotton fabric (%)	77.53	70.24	73.29	72.71

that the stabilizing mechanisms of stabilizers were different. The silver nanoparticles on the cotton fabric using PVP as stabilizer were exposed to air for a long time, these exposed silver nanoparticles would be oxidized to silver oxide and turned black. However, the silver nanoparticles on the cotton fabrics using NL and CL as stabilizer could not be oxidized because they were encapsulated by NL and CL.

Washing fastness of antibacterial cotton fabrics

The poor washing resistance of antibacterial textiles had always been one of the largest obstacles to developing antibacterial textiles. Antibacterial cotton fabrics prepared with three different stabilizers were washed with standard washing method for 10 and 50 times, respectively, and the results are shown in Table 3. The results in Table 3 indicated that sterilizing rates of cotton fabrics finished by using PVP, NL and CL as stabilizer still could meet the requirements of antibacterial textile after 10 and 50 times standard washing, although the sterilizing rates and nano silver contents decreased compared with before washing. Some silver nanoparticles on cotton fabrics did not completely enter the interior of cellulose fibers, but physically attached to the surface of cellulose fibers or to the gaps of the yarns, the binding force (mainly physical adsorption) between these silver

Table 3 Comparison of washing resistance of antibacterial cotton fabrics

Washing times	Index	PVP	NL	CL
0	Silver content on cotton fabric (mg/g)	96.6	92.8	98.1
	Sterilizing rate against *S. aureus* (%)	99.51	99.35	99.41
	Sterilizing rate against *E. coli* (%)	99.49	99.31	99.39
10	Silver content on cotton fabric (mg/g)	90.4	87.6	91.9
	Sterilizing rate against *S. aureus* (%)	99.46	99.24	99.35
	Sterilizing rate against *E. coli* (%)	99.42	99.19	99.31
50	Silver content on cotton fabric (mg/g)	85.3	82.1	85.9
	Sterilizing rate against *S. aureus* (%)	99.11	98.47	98.83
	Sterilizing rate against *E. coli* (%)	99.02	98.42	98.76

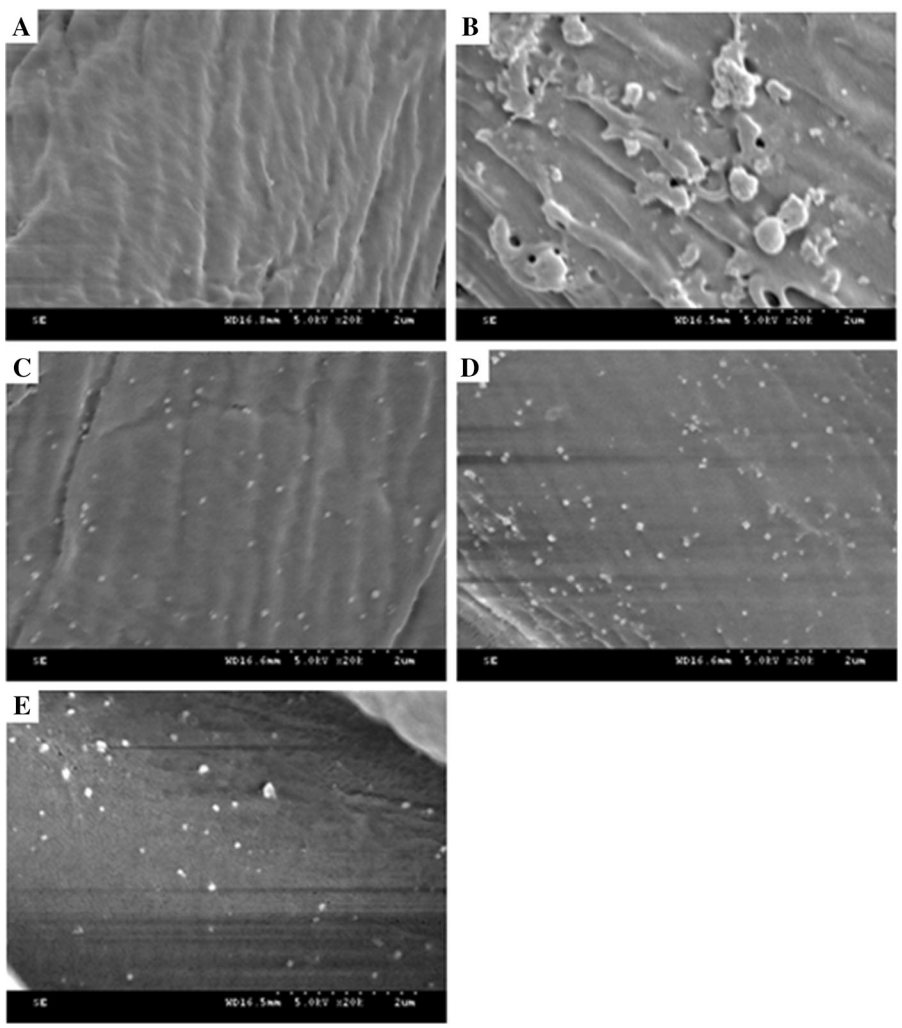


Fig. 4 SEM images of cotton fabrics. **a** Untreated fabrics, **b** without stabilizer, **c** NL as stabilizer, **d** CL as stabilizer, and **e** PVP as stabilizer

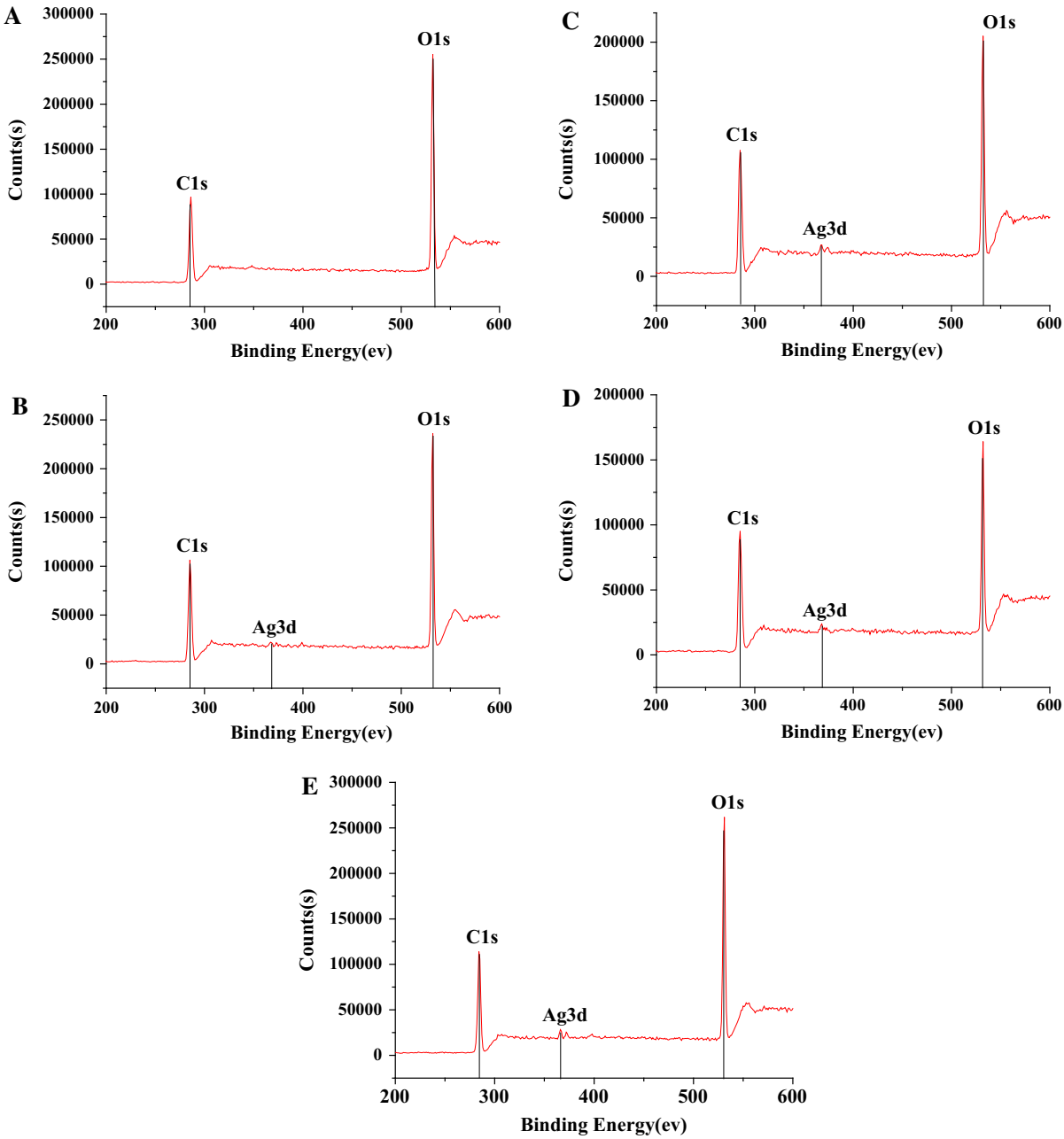


Fig. 5 XPS spectra of cotton fabrics. **a** Untreated fabrics, **b** without stabilizer, **c** NL as stabilizer, **d** CL as stabilizer, and **e** PVP as stabilizer

nanoparticles and cellulose fibers was weak. These silver nanoparticles would fall off the fabrics when they were subjected to the action of the detergents and mechanical forces. Therefore, the sterilizing rate and nano silver content all would decrease after many times standard washing.

Surface morphology of antibacterial fibers

Surface morphologies of antibacterial cotton fabrics and untreated cotton fabrics were observed using SEM, and the results are shown in Fig. 4. The surface of untreated cotton fabric was smooth, but the surface

of the antibacterial cotton fabrics had changed to some extents. As shown in Fig. 4b, the surface of cotton fabric finished by nano silver sols without stabilizer was also covered some silver nanoparticles, but these silver nanoparticles all were agglomerated, and they had low antibacterial properties and poor washing resistance. As seen from Fig. 3c–e, cotton fabrics treated by nano-silver sols using NL, CL and PVP as stabilizer had achieved the desired finishing effect, and silver nanoparticles finished on cotton fabrics were not only small in size but also dispersed uniformly.

XPS analysis of antibacterial fabrics

Antibacterial and untreated cotton fabrics were analyzed using X-ray photoelectron spectroscopy, and the results are shown in Fig. 5 and Table 4. In Fig. 5, antibacterial fabrics (Fig. 3b–e) all appeared very weak double diffraction peaks (because the content of nano silver on the cotton fabric is low) at 368 and 374 eV. The double diffraction peaks corresponded to Ag3d5/2 (368 eV) and Ag3d3/2 (374 eV) of silver. This also indicated that cotton fabrics were successfully finished by silver nanoparticles.

It can be seen from Table 4, the content of nano silver in Sample B was much lower than those of nano silver in Samples C, D and E, and the content of nano silver in Sample D was slightly higher than that of nano silver in Sample C due to the positive charge in CL. In addition, a small amounts of P (characteristic element of liposome) were also found in Samples C and D, and the peak value of P in Fig. 5 was not obvious due to its low level.

Stabilizing mechanism of stabilizers

PVP is a synthetic water-soluble polymer with the general properties of water-soluble polymers, such as film-forming property, colloid protection, agglutinating value, etc. An agglutinant PVP thin film was formed in water, and the prepared silver nanoparticles were uniformly adhered to the thin film. Therefore, the phenomenon of nano silver agglomeration can be avoided by reducing collisions between prepared silver nanoparticles (Fig. 6).

The stabilizing mechanism of NL was totally different from that of PVP. The prepared silver nanoparticles were mostly encapsulated in the bilayer of NL (Fig. 7). A small amounts of unencapsulated

Table 4 Element analysis of cotton fabrics

Element	A	B	C	D	E
C (at%)	58.07	59.87	64.01	67.97	58.3
O (at%)	41.93	36.11	33.9	30.69	38.57
Ag (a %)	–	0.34	0.71	0.78	0.76
P (at%)	–	–	0.21	0.26	–
N (at%)	–	0.15	0.65	0.3	2.37

A untreated fabrics, *B* without stabilizer, *C* NL as stabilizer, *D* CL as stabilizer; *E* PVP as stabilizer

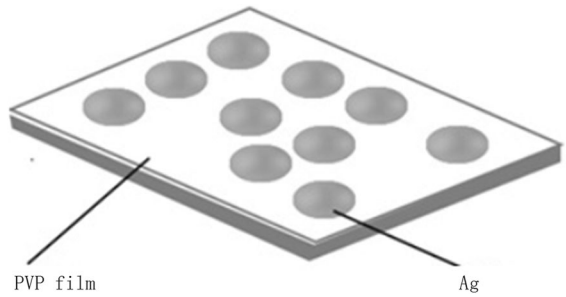


Fig. 6 Mechanisms of stabilization of silver nanoparticles with PVP

silver nanoparticles had a lower collision probability due to the low concentration of silver nanoparticles in solution, so NL could also act as stabilizer of silver nanoparticles. Silver nanoparticles encapsulated by NL were adsorbed to the surface of cellulose fibers and were slowly released from NL when cotton fabric was impregnated in nano silver sols. The dispersity of silver nanoparticles adsorbed on cellulose fibers was uniform because NL had the function of sustained-release silver nanoparticles.

The stabilizing mechanism of CL is almost identical to that of NL (Fig. 8). The sole difference was that the CL themselves are positively charged, while cellulose fibers are negatively charged in water, so more silver nanoparticles encapsulated by CL can be adsorbed to cellulose fibers more quickly in comparison with NL. This may be why the sterilizing rate and nano silver content of cotton fabric finished by using CL as stabilizer was better than that of cotton fabric finished by using NL as stabilizer.

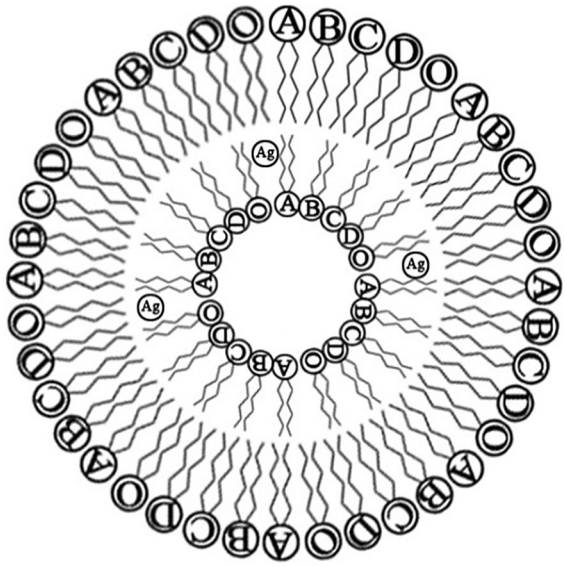


Fig. 7 Proposed mechanism for the interaction of Ag with NL ingredients. A Phosphatidylcholine, B phosphatidylethanolamine, C phosphatidylinositol, D phosphatidic acid, and O other ingredients

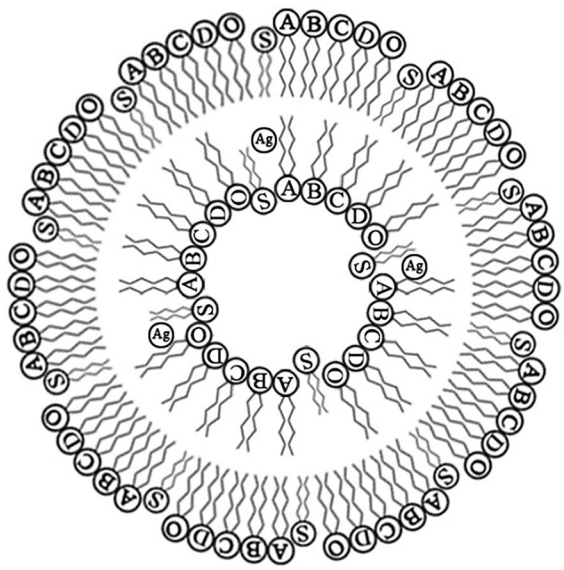


Fig. 8 Proposed mechanism for the interaction of Ag with CL ingredients. A Phosphatidylcholine, B phosphatidylethanolamine, C phosphatidylinositol, D phosphatidic acid, O other ingredients, and S stearamide

Conclusions

Silver nanoparticles were successfully synthesized and stabilized by a simple, environment-friendly method in NL and CL structures, and cotton fabrics were antibacterially finished by nano silver encapsulated in NL and CL. Prepared Ag-liposome nanocomposites were characterized by XRD and TEM, and prepared antibacterial cotton fabrics were analyzed by SEM and XPS. The sterilizing rate and nano silver content of cotton fabric finished by using CL as stabilizer were better than those of cotton fabric finished by using NL as stabilizer due to the positive charge of CL. The whiteness of antibacterial cotton fabrics using NL and CL as stabilizer were obviously higher than that of one using PVP as stabilizer, although the sterilizing rates of antibacterial cotton fabrics using three different stabilizers were not different. Sterilizing rates of antibacterial cotton fabrics using PVP, NL and CL as stabilizers still could meet the requirements of antibacterial textile after 10 and 50 times standard washing, although the sterilizing rates and nano silver contents decreased compared with before washing. These results indicated the potential of nanoliposomes, especially CL, as a novel stabilizer for nano silver antibacterial application. The stabilizing mechanisms of PVP, NL and CL were proposed.

Acknowledgments This research was supported by the Youth Science Fund of Heilongjiang Province of China (QC2017079), the Science and Technology Project of Qiqihar (GYGG-201513), the Fundamental Research Funds in Heilongjiang Province Universities (135209208), and the Fundamental Research Funds in Heilongjiang Province Universities (135109246).

References

Abbasi E, Milani M, Aval SF, Kouhi M, Akbarzadeh A, Nasrabadi HT, Nikasa P, Joo SW, Hanifehpour Y, Nejati-Koshki K, Samiei M (2014) Silver nanoparticles: synthesis methods, bio-applications and properties. Crit Rev Microbiol 42:173–180. https://doi.org/10.3109/1040841X.2014.912200

Ahani E, Montazer M, Toliyat T, Mahmoudi RM, Harifi T (2017) Preparation of nano cationic liposome as carrier membrane for polyhexamethylene biguanide chloride through various methods utilizing higher antibacterial activities with low cell toxicity. J Microencapsul 34:121–131. https://doi.org/10.1080/02652048.2017.1296500

Aisha AF, Majid AM, Ismail Z (2014) Preparation and characterization of nano liposomes of *Orthosiphon stamineus* ethanolic extract in soybean phospholipids. BMC Biotechnol 14:23. https://doi.org/10.1186/1472-6750-14-23

Ali ZA, Roslan MA, Yahya R, Wan SW, Puteh R (2017) Eco-friendly synthesis of silver nanoparticles and its larvicidal property against fourth instar larvae of *Aedes aegypti*. IET Nanobiotechnol 11:152–156. https://doi.org/10.1049/iet-nbt.2015.0123

Arokiyaraj S, Vincent S, Saravanan M, Lee Y, Oh YK, Kim KH (2017) Green synthesis of silver nanoparticles using *Rheum palmatum* root extract and their antibacterial activity against *Staphylococcus aureus* and *Pseudomonas aeruginosa*. Artif Cells Nanomed Biotechnol 45:372–379. https://doi.org/10.3109/21691401.2016.1160403

Baptista ALF, Coutinho PJG, Real Oliveira MECD, Rocha Gomes JIN (2003a) Effect of pH on the control release of microencapsulated dye in lecithin liposomes. II. J Liposome Res 13:123–130. https://doi.org/10.1081/LPR-120020315

Baptista ALF, Coutinho PJG, Real Oliveira MECD, Rocha Gomes JIN (2003b) Effect of temperature and surfactant on the control release of microencapsulated dye in lecithin liposomes. I. J Liposome Res 13:111–121. https://doi.org/10.1081/LPR-120020314

Bothun GD (2008) Hydrophobic silver nanoparticles trapped in lipid bilayers: size distribution, bilayer phase behavior, and optical properties. J Nanobiotechnol 6:13. https://doi.org/10.1186/1477-3155-6-13

Chen Q, Mi T, Chen G, Li Y (2017) Green synthesis of nano-silver particles using plant active substance from lemongrass extract. BioRes 12:7096–7106. https://doi.org/10.15376/biores.12.4.7084-7095

Crabtree JH, Burchette RJ, Siddiqi RA, Huen IT, Hadnott LL, Fishman A (2003) The efficacy of silver-ion implanted catheters in reducing peritoneal dialysis-related infections. Periton Dialysis Int 23:368–374

Daraee H, Etemadi A, Kouhi M, Alimirzalu S, Akbarzadeh A (2014) Application of liposomes in medicine and drug delivery. Artif Cells Nanomed Biotechnol 44:381–391. https://doi.org/10.3109/21691401.2014.953633

Dzenis Y (2004) Spinning continuous fibers for nanotechnology. Science 304:1917–1919. https://doi.org/10.1126/science.1099074

El-Zawahry MM, El-Shami S, El-Mallah MH (2007) Optimizing a wool dyeing process with reactive dye by liposome microencapsulation. Dyes Pigments 74:684–691. https://doi.org/10.1016/j.dyepig.2006.04.014

Guo Q, Zhao Y, Dai X, Zhang T, Yu Y, Zhang X, Li C (2017) Functional silver nanocomposites as broad-spectrum antimicrobial and biofilm-disrupting agents. ACS Appl Mater Interfaces 9:16835–16848. https://doi.org/10.1021/acsami.7b02775

Hirano S, Wakasa Y, Saka A, Yoshizawa S, Oya-Seimiya Y, Hishinuma Y, Nishimura A, Matsumoto A, Kumakura H (2003) Preparation of Bi-2223 bulk composed with silver-alloy wire. Physica C 392:458–462. https://doi.org/10.1016/S0921-4534(03)01222-X

Jiang H, Manolache S, Wong ACL, Denes FS (2004) Plasma-enhanced deposition of silver nanoparticles onto polymer and metal surfaces for the generation of antimicrobial characteristics. J Appl Polym Sci 93:1411–1422. https://doi.org/10.1002/app.20561

Ki HY, Kim JH, Kwon SC, Jeong SH (2007) A study on multifunctional wool textiles treated with nano-sized silver. J Mater Sci 42:8020–8024

Marti M, Adela M, Parra JL, Coderch L, Serra S (2001) Dyeing wool at low temperatures: new method using liposomes. Text Res J 71:678–682

Martí M, Coderch L, Maza ADL, Parra JL (2007) Liposomes of phosphatidylcholine: a biological natural surfactant as a dispersing agent. Color Technol 123:237–241. https://doi.org/10.1111/j.1478-4408.2007.00089.x

Morones JR, Elechiguerra JL, Camacho A, Holt K, Kouri JB, Ramírez JT, Yacaman MJ (2005) The bactericidal effect of silver nanoparticles. Nanotechnology 16:2346–2353. https://doi.org/10.1088/0957-4484/16/10/059

Neves LF, Duan J, Voelker A, Khanal A, Mcnally L, Steinbachrankins J, Ceresa BP (2016) Preparation and optimisation of anionic liposomes for delivery of small peptides and cDNA to human corneal epithelial cells. J Microencapsul 33:391–399. https://doi.org/10.1080/02652048.2016.1202343

Parham S, Nemati M, Sadir S, Bagherbaigi S, Wicaksono DHB, Nur H (2017) In situ synthesis of silver nanoparticles for Ag-NP/cotton nanocomposite and its bactericidal effect. J Chin Chem Soc 64:1286–1293. https://doi.org/10.1002/jccs.201700157

Rafique M, Sadaf I, Rafique MS, Tahir MB (2016) A review on green synthesis of silver nanoparticles and their applications. Artif Cells Nanomed Biotechnol 45:1272–1291. https://doi.org/10.1080/21691401.2016.1241792

Ren X (2002) Enhancement of glucose biosensor sensitivity by addition of Ag-Au nanoparticles. Sci Technol Eng 2:15–16

Salaheldin HI, Almalki MHK, Hezma AEM, Osman GEH (2017) Facile synthesis of silver nanoparticles mediated by polyacrylamide-reduction approach to antibacterial application. IET Nanobiotechnol 11:448–453. https://doi.org/10.1049/iet-nbt.2016.0135

Shaker S, Gardouh AR, Ghorab MM (2017) Factors affecting liposomes particle size prepared by ethanol injection method. Res Pharm Sci 12:346–352. https://doi.org/10.4103/1735-5362.213979

Sheng Z, Yang L (2017) Potential impacts of silver nanoparticles on bacteria in the aquatic environment. J Environ Manage 191:290–296. https://doi.org/10.1016/j.jenvman.2017.01.028

Singh H, Du J, Yi TH (2017) Kinneretia THG-SQI4 mediated biosynthesis of silver nanoparticles and its antimicrobial efficacy. Artif Cells Nanomed Biotechnol 45:602–608. https://doi.org/10.3109/21691401.2016.1163718

Telegin FY, Belokurova OA, Shchitova NP (2013) Application of liposomes in the textile industry. Russ J Gen Chem 83:214–219. https://doi.org/10.1134/S1070363213010428

Visht S, Awasthi R, Rai R, Srivastav P (2014) Development of dehydration-rehydration liposomal system using film hydration technique followed by sonication. Curr Drug Deliv 11:763–770. https://doi.org/10.2174/1567201811666140910122945

Zhang L, Webster TJ (2009) Nanotechnology and nanomaterials: promises for improved tissue regeneration. Nano Today 4:66–80. https://doi.org/10.1016/j.nantod.2008.10.014