Research Article

Sticky silver nanoparticles and surface coatings of different textile fabrics stabilised by *Muntingia calabura* leaf extract

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Abstract

Permanent deposition of silver nanoparticles (AgNPs) on the surface of textile fibre is essential for the long-term medical application of antibacterial textile products. This study aims to propose a new green method of using the pure leaf extract of *Muntingia calabura* and to create a permanent deposition of AgNPs on the fabric surfaces of cotton, polyester and nylon. The appearance of darker colour confirms the deposition of AgNPs on the fabric fibres. The capacity of water absorption decreased by 9.3, 12.0 and 23.0% and the textile density increased by 10.4, 12.3 and 5.9% were verified for the fabric fibres of cotton, polyester and nylon, respectively, after binding with AgNPs. The antibacterial activity of the cotton, polyester and nylon fabrics against *Escherichia coli* is better than that against *Chromobacterium haemolyticum* and then is better than that against *Bacillus cereus*. The results obtained using the new green method of processing heat treatment experiments by using the pure leaf extract to penetrate AgNPs inside the fabric fibres may contribute to advancing the application of antibacterial textile products for medical uses.

Keywords Antibacterial activity · Green method · *Muntingia calabura* · Pure leaf extract · Silver nanoparticles · Textile fibre

1 Introduction

Textiles are used worldwide in many traditional crafts such as sewing, quilting and embroidery for the numerous applications but can also serve as medium for growth and transportation of microorganisms. Several strategies have been proposed to improve the properties of textile fibres, including the modification of surface using synthetic organic compounds such as chitosan, triclosan, quaternary ammonium compounds, polybiguanides, N-halamines and silver nanoparticles (AgNPs) to produce an antibacterial textile surface [35]. Antibacterial textiles would be appropriate attire for many applications that require a strict cleaning schedule to maintain hygiene, health and

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happiness levels. Therefore, they are beneficially used for the medical clinics, hospitals, laboratories and health centres. The use of antibacterial AgNPs impregnated textiles in a long-term care ward may significantly reduce fever, antibiotic consumption and related treatment costs associated with the diagnosis and management of infection complications. The use of AgNPs has been reported effective as the treatment against burns, wounds and several bacterial infections and can either totally prevent, delay or otherwise reduce food spoilage [19, 43, 56]. The effectiveness of AgNPs has been investigated for their antimicrobial characteristics against a broad range of microorganisms including bacteria, yeast and fungi [14, 62]. The application of AgNPs deposited on fabric fibre has gained a significant attention and has become more apparent in many medical applications of such as first-aid plasters, sterile surgical dressings, incision drapes, bandages and advance medical devices for the treatment of wounds [37, 53].

AgNPs deposition on the fabric surface or other material surfaces can be accomplished by using the various techniques such as immersion, layer-by-layer deposition of AgNPs films and sonochemical deposition [7, 40, 41, 47, 64]. Green synthesis of AgNPs to inhibit the pathogenic bacteria growth has been investigated using the turmeric extracts and the leave extracts of *Camellia sinensis* [2, 38]. The deposition of AgNPs on the surface of textile fabrics such as cotton, wool, polyester, silk, cotton/polyester blend, regenerated cellulose and polyamide has been proposed to impart new functionality and improved performance [18]. However, the laundry of clothing and other textiles may release AgNPs from the fabric surface [7]. Therefore, the methods of coating the textile fabrics with AgNPs to remain a permanent deposition need to be continually revised and improved. The applications of binder, cross linkable polymer and crosslinking agents have been suggested for permanently binding AgNPs deposition on the fabric surface [6, 8, 12, 13, 22, 34, 46]. Nevertheless, the ways of attracting AgNPs potentially involve the hazardous chemicals and can be particularly harmful for the medical applications of using the antibacterial textiles to diminish new complications. It is suggested that new method of processing heat treatment experiments by using a pure leaf extract can penetrate AgNPs inside the fabric fibres and can avoid the release of AgNPs caused by washing of antibacterial textile fabrics. Even though the green synthesis of AgNPs stabilised using the *Bridelia retusa* leaf extract and making use of the *Vigna mungo* hull have been investigated to pave the way for eco-friendly utilisation [60, 61], the deposition of AgNPs onto the surface of different textile fabrics is still not fully understood. The objectives of this study are (1) to propose a new green method of using the pure leaf extract of *Muntingia calabura* for attracting AgNPs onto textile fibres and (2) to investigate the behaviour and antibacterial effect of AgNPs deposition on the different fabric surfaces of cotton, polyester and nylon without the addition of chemical substance.

2 Materials and methods

2.1 Materials

This study used the chemical reagent of $AgNO_3$ originally delivered from QReC (Auckland, New Zealand). The leaves of *M. calabura* were collected from a location around the campus of Universiti Teknologi Malaysia, Johor Bahru, Malaysia. The plant of *M. calabura* has been authenticated by Dr. A. Balasubramanian with its authentication number of AUT/PUS/068 dated on 17 December 2014 [25]. The nylon membrane of 0.45 µm purchased from Whatman® Nylon Membranes—Sigma-Aldrich (St. Louis, MO, USA) was used as filter. The solutions were prepared using high-purity water with its resistivity of 18.2 MΩ cm (at 25 °C), produced by the arium® Water Purification Systems (Sartorius Malaysia Sdn Bhd, Kuala Lumpur, Malaysia). The textile fabrics of 100% cotton with its weight of 135 g/m^2, 100% polyester with its weight of 155 g/m^2 and 100% nylon with its weight of 102 g/m^2 were obtained from SBK Textile Trading, Johor Bahru, Malaysia. The culture media for the bacterial growth were prepared using the agar powder delivered from Oxoid Ltd (Nutrient Agar CM0003, Oxoid, Basingstoke, UK). Two bacteria of *Escherichia coli* (*E. coli*) and *Bacillus cereus* (*B. cereus*) were obtained from the Faculty of Biosciences and Medical Engineering, Universiti Teknologi Malaysia.

2.2 Extraction of the *Muntingia calabura* leaves

The sample of *M. calabura* leaves was washed three times with tap water and then three times with ultrapure water to remove the contaminations [31]. A 20 g of the leave sample was added into a beaker containing 200 mL of the ultrapure water and then heated at 250 °C for 30 min and then cooled at room temperature. The extraction solution was filtered through with a 45 µm nylon membrane using the DURAN® filtering apparatus to obtain a pure leaf extract. The solution of pure leaf extract was stored in the fridge at 7 °C for the future uses.

2.3 Deposition of AgNPs inside the textile fabric

A solution of 0.15 M $AgNO_3$ was prepared by dissolving 29.25 g of $AgNO_3$ in 100 mL of ultrapure water. A textile fabric of 2 × 2 cm was immersed in 5 mL of 0.15 M $AgNO_3$ solution in a beaker of 50 mL, stirring constantly for 2 h, and then slowly added 5 mL of the pure leaf extract solution in

a dark environment. The mix solution was then heated at 70 °C for 10 min with constant magnetic stirring and then dried at 80 °C for 10 min.

2.4 Measurements of water absorption and textile fabric density

The absorption of water by a textile fabric is essential for the metabolic activity of bacteria and can be determined after 1 h immersion in distilled water. Therefore, the sample was weighed before and after immersion and then the absorption of water can be calculated using the equation [1] of:

$$W = \frac{m_a}{m_o} \times 100\% \quad (1)$$

where W is the water absorption by the textile fabric (in %), m_a is the mass of textile fabric after the absorption of water (in g), and m_o is the mass of textile fabric before the absorption of water (in g).

The density of textile fabric before and after the absorption of water can be determined using the equation of:

$$D = \frac{m}{A} \quad (2)$$

where D is the textile fabric density (in g/m^2), m is the mass of textile fabric (in g), and A is the area of textile fabric (in m^2).

2.5 Bacterial identification

This study used three bacterial strains to test the antibacterial activity of the textile fabrics after biding with AgNPs. Two bacterial strains of *E. coli* and *B. cereus* have been identified delivering from the Faculty of Biosciences and Medical Engineering, Universiti Teknologi Malaysia. One strain of bacteria was isolated from the wastewater collected from a domestic wastewater treatment plant managed by Indah Water Konsortium Sdn Bhd located at Taman Universiti, Johor Bahru, Malaysia. The Polymerase Chain Reaction (PCR) was used to amplify the specific region of the 16s rRNA gene of unknown bacteria and to generate the DNA target sequence of interest for the identification of bacterial strains found in the wastewater environment [9]. The strain of *Chromobacterium haemolyticum* (*C. haemolyticum*) was identified using the basic local alignment search tool (BLAST) carried out by the First BASE Laboratories Sdn Bhd, Selangor, Malaysia.

2.6 Characterisation of the textile fabric surfaces

The characterisation of three textile fabrics of cotton, polyester, and nylon was carried out for each sample with three replicates, without and with binded AgNPs. The surface morphology of textile fabric was examined using the Field Emission Scanning Electron Microscopy (FESEM) of Zeiss SUPRA 35VP model, which was operated at 5 kV. The distribution of AgNPs and other elements on the surface of textile fabric was examined using the Scanning Electron Microscopy with Energy Dispersive X-ray Spectroscopy (SEM–EDX) of Hitachi S-3400N model, operated at 15 kV. For the purpose of this work, the SEM–EDX was equipped with the Bruker QUANTAX 200 software.

2.7 Inhibition zone test

A standardised approach is needed to assess AgNPs toxicity to both Gram-negative and Gram-positive bacteria [33]. The culture media of Nutrient Agar (NA) for bacterial growth were prepared by adding 20 g of agar powder in 1 L of ultrapure water. The NA along with petri dishes was sterilised by heating in an autoclave. Approximately 25 mL of the liquefied NA was poured into a petri dish and then spread 0.1 mL of the liquid bacterial culture on the NA surface. A textile fabric after binded AgNPs was put on the petri dish and then placed in an oven at 37 °C for 5 d. Clear zone surrounding the bacterial growth was measured for quantifying the zone of inhibition. The test of textile fabric without binded AgNPs was performed as a control test, using the same procedure.

3 Results and discussion

3.1 Results

3.1.1 Colour transformation of the textile fabrics

The results (Figs. 1, 2, 3) of changed colour may indicate the adsoption of AgNPs on the surface of textile fabric. The transformation of colour from red (see Fig. 1a) to black (see Fig. 1b), from tan (see Fig. 2a) to black (see Fig. 2b), and from orange (see Fig. 3a) to black (see Fig. 3b) was verified for textile fibre of 100% cotton, 100% polyester, and 100% nylon, respectively. The appearance of darker colour may confirm the adsorption of AgNPs onto the fabric surface of cotton [4, 44]. The fabric surface of wool treated with AgNPs can enhance the antibacterial properties [20].

3.1.2 Water absorption and textile fabric density

The presence of AgNPs deposition on the surface of textile fabric can decrease the capacity of water absorption. The results of water absorption measurement show that (1) the capacity of water absorption for cotton woven fabric decreases by 9.3%, (2) the capacity of water absorption for polyester woven fabric decreases by

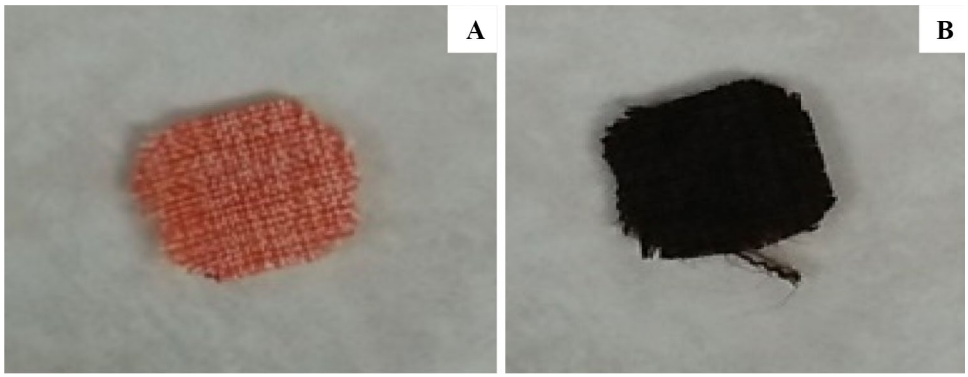

Fig. 1 Transformation of colour on the surface of textile fabric, with **a** 100% cotton before binded AgNPs and **b** 100% cotton after binded AgNPs

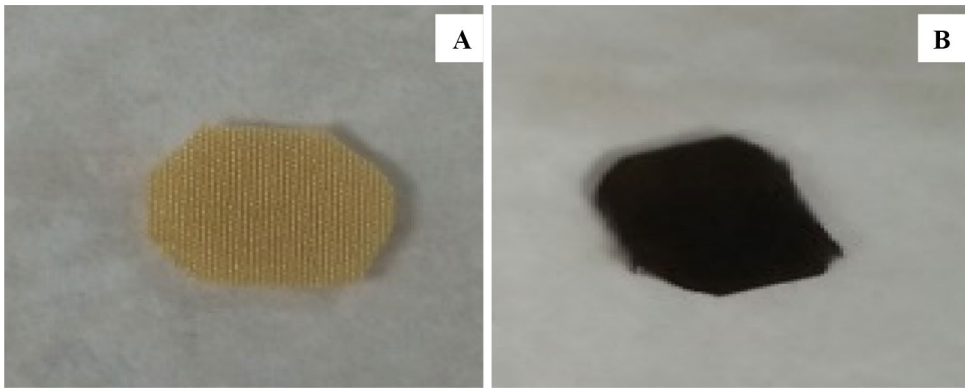

Fig. 2 Transformation of colour on the surface of textile fabric, with **a** 100% polyester before binded AgNPs and **b** 100% polyester after binded AgNPs

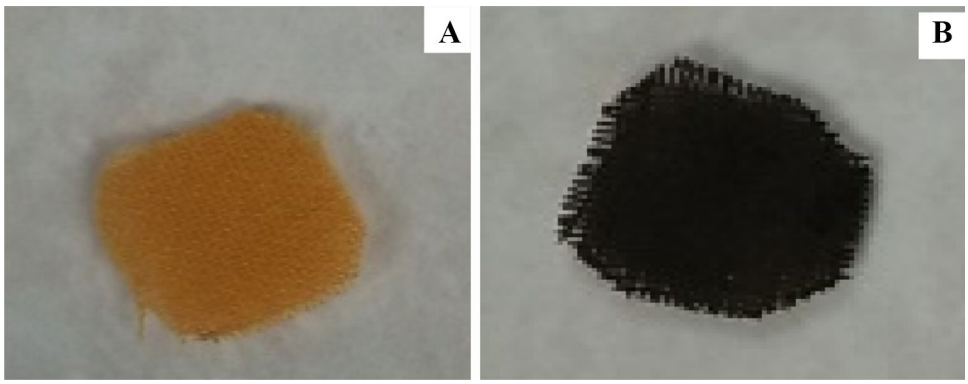

Fig. 3 Transformation of colour on the surface of textile fabric, with **a** 100% nylon before binded AgNPs and **b** 100% nylon after binded AgNPs

12.0%, and (3) the capacity of water absorption for nylon woven fabric decreases by 23.0%. A decresae in the water absorption capacity of AgNPs embedded nylon fibres is greater than that of AgNPs embedded polyester fibres and then is greater than that of AgNPs embedded cotton fibres. Density of textile fabric increases with AgNPs deposited on its surface. The results of density measurement show that (1) the density of cotton woven fabric increases by 10.4% from 135 to 149 g/m^2, (2) the density of polyester woven fabric increases by 12.3% from 155 to 174 g/m^2, and (3) the density of nylon woven fabric increases by 5.9% from 102 to 108 g/m^2.

3.1.3 Surface morphology of the textile fabrics

The surface morphology of three textile fabrics was observed using the FESEM analysis before and after binded AgNPs, as shown in Figs. 4, 5 and 6. The scanning of cotton surface morphology (Fig. 4a, b) shows that (1) the FESEM image of Fig. 4a for pristine cotton fabric has a structure of the smooth longitudinal fibrillar cotton fibers without contaminant particles and (2) the FESEM image (Fig. 4b) of micro-rough surface structure indicates the AgNPs deposited on the cotton fabric surface. The deposition of AgNPs on the cotton fabric surface becomes clearly apparent in

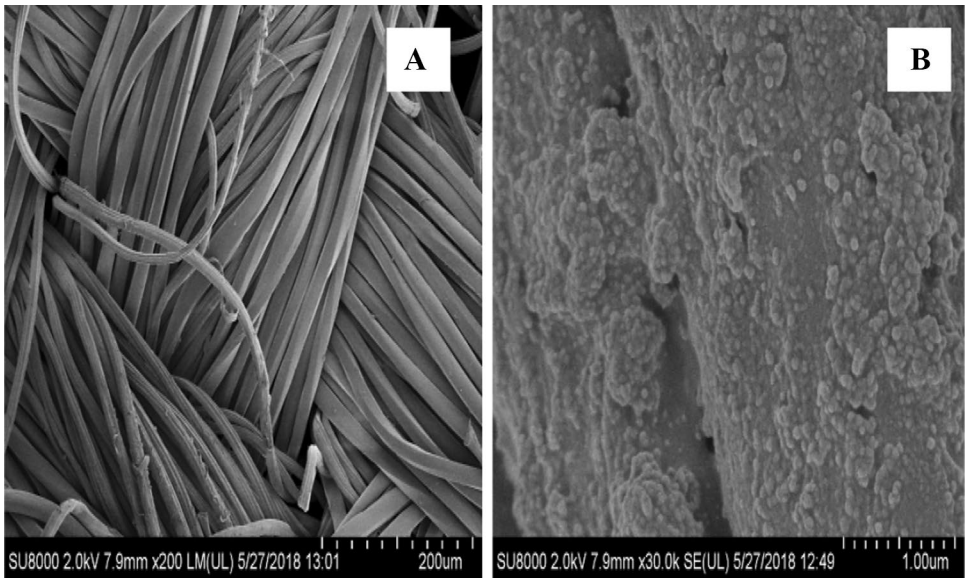

Fig. 4 FESEM image of the textile fabric surface, with **a** 100% cotton before binded AgNPs and **b** 100% cotton after binded AgNPs at 30 k magnification

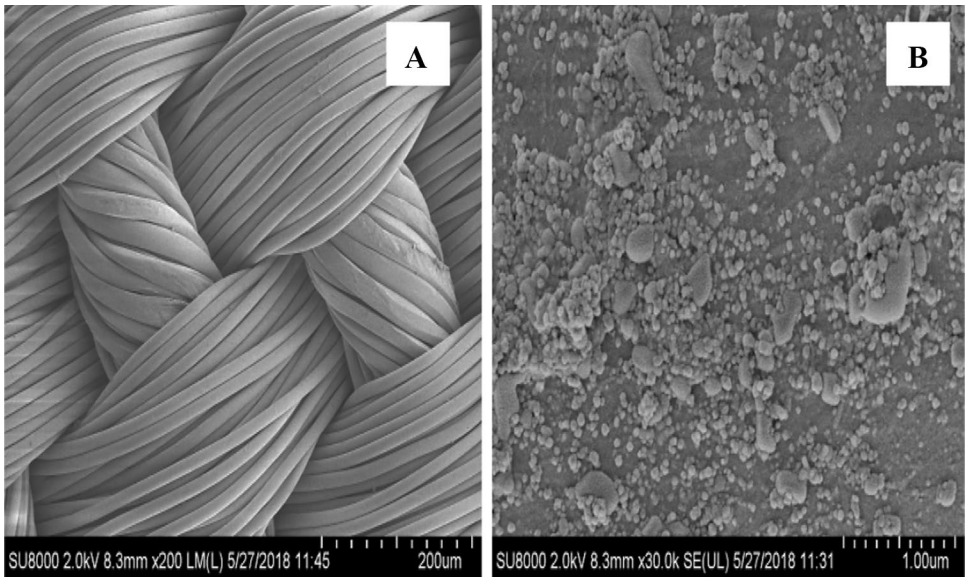

Fig. 5 FESEM image of the textile fabric surface, with **a** 100% polyester before binded AgNPs and **b** 100% polyester after binded AgNPs at 30 k magnification

the FESEM image of Fig. 4b with 30 k magnification, which shows the AgNPs deposition almost entirely covered cotton fabric surface. The scanning of polyester surface morphology (Fig. 5a, b) shows that (1) it is not apparent AgNPs contamination observed on the FESEM image of Fig. 5a for pristine polyester fabric and (2) the FESEM image of Fig. 5b with appeared micro-rough surface structure may indicate the AgNPs deposited on the polyester fabric surface. The deposition of AgNPs on the polyester fabric surface in the forms of agglomerates and single particles may reveal the polyester fabric surface almost entirely covered by the AgNPs deposition, as can be observed in the FESEM image of Fig. 5b with 30 k magnification. It can be seen from the scanning of nylon surface morphology (see Fig. 6a, b) that (1) the FESEM image of Fig. 6a has a structure of smooth longitudinal fibrillar nylon fibres without any contaminant particles on the surface of pristine nylon fabric and (2) the FESEM image of Fig. 6b indicates the AgNPs deposition on nylon fabric surface with the appearance of micro-rough structure. The deposition of AgNPs on the nylon fabric surface is clearly apparent at 30 k magnification, which shows almost entirely covered by AgNPs deposition (see Fig. 6b).

3.1.4 AgNPs distribution and elemental composition

In spite of the X-ray diffraction technique can be used to analyse structural features of the textile fabrics and the Fourier-transform infrared spectroscopy can be used to detect structural variation of semicrystalline polymers on the surface of textile fabric before and after binded

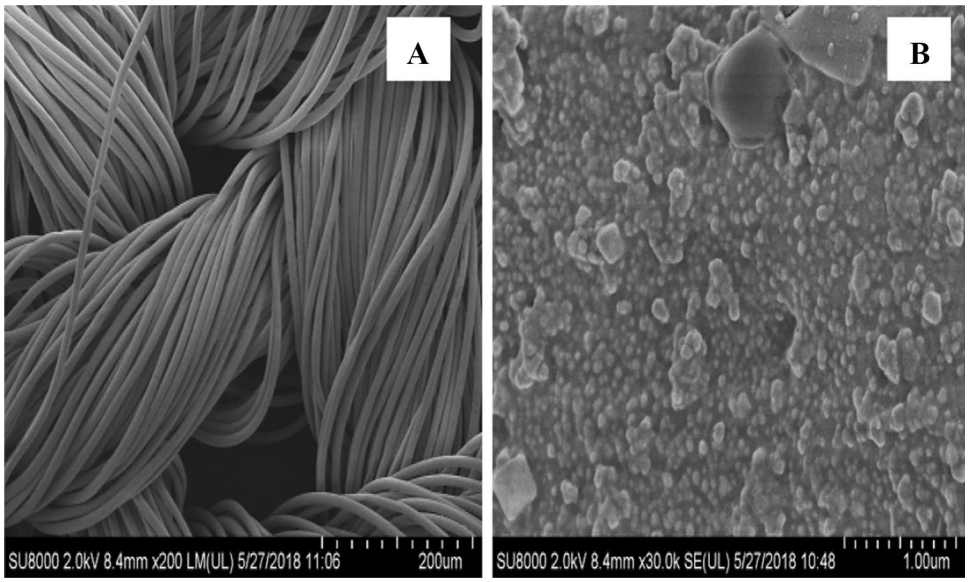

Fig. 6 FESEM image of the textile fabric surface, with **a** 100% nylon before binded AgNPs and **b** 100% nylon after binded AgNPs at 30 k magnification

AgNPs, this study only focuses on the investigation of morphological change and elemental composition on three textile fabric surfaces. The results (Supplementary materials: Figs. IA, C, E) of morphological change investigated by the SEM–EDX technique show the AgNPs distribution on the fabric surfaces of cotton, polyester and nylon. The agglomerates of AgNPs cover some parts of the cotton fabric surface in spite of the unequal distribution of AgNPs relates more with deposition amongst smaller groups of AgNPs precipitates (see Supplementary materials: Fig. IA). The uniform distribution of AgNPs appears on the surface of polyester fabric there is not apparent the agglomerates of AgNPs (see Supplementary materials: Fig. IC). The presence of AgNPs on the surface of nylon fabric can be seen in form of the agglomerates while the very small crystalline AgNPs are dispersed and distributed over half of the nylon fabric surface (see Supplementary materials: Fig. IE).

The SEM–EDX spectrum analysis of elemental composition can verify the AgNPs suspension on the fabric surfaces of cotton, polyester and nylon (see Supplementary materials: Figs. IB, D, F). The SEM–EDX spectrum recorded showing a peak approximately near 3 keV confirms the presence of silver [59]. The percent compositions of carbon, oxygen, silver and nitrogen on the cotton fabric surface are as high as 46.3, 26.8, 24.8 and 2.0%, respectively (see Supplementary materials: Fig. IB). The percent compositions of carbon, oxygen, silver and nitrogen on the polyester fabric surface are as high as 52.7, 29.7, 13.4 and 4.2%, respectively (see Supplementary materials: Fig. ID). The percent compositions of carbon, oxygen, silver and nitrogen on the nylon fabric surface are as high as 42.1, 27.8, 23.4 and 6.7%, respectively (see Supplementary materials: Fig. IF).

3.1.5 Antibacterial properties of the textile fabrics

Antibacterial properties of the cotton, polyester, and nylon fabric surfaces after binded AgNPs were examined using three different bacterial strains of *E. coli*, *B. cereus*, and *C. haemolyticum*. The results (Supplementary materials: Fig. II; see Table 1) of antibacterial examination show that the inhibition zones are all not apparent on the surfaces of cotton, polyester, and nylon fabric before binded AgNPs (see Supplementary materials: Figs. IIA, E, I). The inhibition zones for Gram-negative bacteria *E. coli* after binded AgNPs are all clearly apparent on the surfaces of cotton, polyester, and nylon fabric with the large zones of 6.33 ± 2.08, 3.33 ± 0.58, and 4.33 ± 0.58 mm, respectively (see Supplementary materials: Figs. IIB, C, D). The inhibition zones for new isolated Gram-negative bacteria *C. haemolyticum* after binded AgNPs are all clearly apparent on the surfaces of cotton, polyester and nylon fabric with the large zones of 5.67 ± 0.58, 2.33 ± 0.58 and 2.00 ± 1.00 mm, respectively (see Supplementary materials: Figs. IIF, G, H). The inhibition zones for Gram-positive bacteria *B. cereus* after binded AgNPs are all clearly apparent on the surfaces of cotton, polyester, and nylon fabric with the large zones

Table 1 Zone of inhibition for three tested bacterial strains of *E. coli*, *B. cereus* and *C. haemolyticum* on fabric surfaces of cotton, polyester, and nylon after binded AgNPs

Bacterial strain	Zone of inhibition (mm)		
	Cotton fabric	Polyester fabric	Nylon fabric
E. coli	6.33 ± 2.08	3.33 ± 0.58	4.33 ± 0.58
B. cereus	2.00 ± 0.00	2.33 ± 0.58	2.33 ± 0.58
C. haemolyticum	5.67 ± 0.58	2.33 ± 0.58	2.00 ± 1.00

of 2.00 ± 0.00, 2.33 ± 0.58 and 2.33 ± 0.58 mm, respectively (see Supplementary materials: Figs. IIJ, K, L).

3.2 Discussion

In spite of the AgNPs exhibits yellowish brown colour caused by the excitation of surface plasmon vibrations [20, 21], the effect of interaction between pure leaf extract of *M. calabura* and AgNPs on the property of fabric surfaces may alter the colour of AgNPs deposition to darker (see Figs. 1, 2, 3). This would be due to AgNPs excites the resonance effect of light trapping when pairing with dielectric materials of cotton, polyester, and nylon [66]. The sensitivity of plasmon resonance to size, shape, and metal composition may cause different sizes and forms in the deposition of AgNPs [26]. The examinations of surface morphology, AgNPs distribution, element composition, and antibacterial property of AgNPs embedded textile fibres are important for intended uses of the textile fabrics [35]. A new green method using a pure leaf extract can reduce environmental impact of smart textiles for state-of-the-art products and future developments [22]. The advantage of mixing AgNPs with leaf extract of *M. calabura* can penetrate AgNPs inside the fabric fibres to ensure a permanent colour and antibacterial property of the textile fabrics. In spite of the extract of *M. calabura* contains many flavanoids as bioreductor compounds [65], the transformation of Ag^+ to Ag_2O as shown with a dark colour may occur by heating the solution containing of $AgNO_3$, *M. calabura* extract, and textile fabric at 70 °C for 10 min and can be described by the chemical reaction: $2Ag^+ + 2OH^- \rightarrow Ag_2O + H_2O$ [55]. This study suggested that the future experiment would be necessary to perform XRD or XPS analysis of the Ag_2O formation on the surface of textile fabric to verify the real state of silver in the AgNPs.

The water absorption property of a textile fabric refers to the capacity of fibre to retain a level of moisture, which might be useful in facilitating the growth of bacteria. A modification of fibre surface by embedding AgNPs can reduce the capacity of water absorption due to the deposition of AgNPs may alter the porosity, capillary pressure, and pore size distribution [29]. Hydrophobic property of AgNPs can act as a barrier to reduce contact angle between fibre and water. The capillary penetration of AgNPs on the cotton fibre can reduce the capacity of water absorption by 9.3%. The deposition of AgNPs on the surface of polyester fibre can reduce the absorption of water by 12.0%. This may relate to a simultaneous capillary penetration and imbibition by fibres. The deposition of AgNPs on the surface of nylon fibre can reduce the water absorption by 23.0%. This can be related to simultaneous capillary penetration, imbibition by fibers, and AgNPs deposited on the surface of fibers [23].

The measurement of textile fabric density helps explain the thickness of AgNPs coated on the fibre surface. The density of cotton fabric increases by 10.4% from 135 to 149 g/m^2 after the deposition of AgNPs as a result of forming a hierarchical structure [49]. The density of polyester fabric increases by 12.3% from 155 to 174 g/m^2 there is due to the uniform distribution of AgNPs on the surface of fibre can easily increase the thickness of film layer with increasing of the AgNPs deposition on the polyester fabric [15]. The density of nylon fabric only increases by 5.9% from 102 to 108 g/m^2 due to the layer of the AgNPs thin film deposites on the surface of nylon fabric; very small crystalline AgNPs may distribute over half of the nylon fibre surface [7].

The surface morphology of the pristine cotton, polyester, and nylon fabrics shows a smooth longitudinal structure of the textile fibres before binded AgNPs due to the contamination of AgNPs does not appear on the fabric surface (see Figs. 4a, 5a, 6a). A technological intervention related to the application of AgNPs has an immense use in the future [57]. The accurrance (see Figs. 4b, 5b, 6b) of rough fibre surface can be observed after binding with AgNPs because of the deposition of AgNPs may make a modification of the surface morphology of the textile fabrics [7, 49]. The formation of single particles and agglomerates in different sizes of the microparticles can be observed in Figs. 4b, 5b and 6b due to each fabric surface has a unique interaction between AgNPs and textile fibre [32].

Mapping the spatial distribution of AgNPs on the surface of textile fabric can be done based on the SEM–EDX investigation. A heat treatment experiment of using the leaf extract of *M. calabura* is able to bind AgNPs with fabric surface in typical form, size, orientation, and the intensity of interaction with fibre, depending on the textile fabric type (see Supplementary materials: Figs. IA, C, E). The agglomerates of AgNPs occurred at some parts of the cotton fabric surface (see Supplementary materials: Fig. IA) are due to soft and fluffy staple fibre of cotton has higher flexibility and can agglomerate AgNPs more effectively (Jones, [17]. The uniform distribution of AgNPs observed on the polyester fabric surface as shown in Fig. IC could be due to more condensation polymer of polyester, which contain ester functional group in their main chain, can interact with AgNPs to disperse microparticles uniformly [16]. This is mainly affected by its organic matter content [10]. The rare agglomerates of AgNPs and very small AgNPs crystalline observed on the nylon fabric surface as shown in Fig. IE could be due to hydrophilic material of nylon can seep water into the fibres more easily [39]. The use of polyester fabric with AgNPs uniformly distributed on the fibre surface as antibacterial textile could be better than that of cotton and nylon fabrics due to the maximum entropy can

achieve a good performance of the structural reliability when the probability distribution is uniform [36].

The element composition on the surface of the textile fabrics was analysed based on the SEM–EDX spectra (see Supplementary materials: Figs. IB, D, F). The elemental analysis confirms the presence of Ag^+ ions due to the SEM–EDX images display a spectral peak at 3 keV corresponding to metallic silver [45, 63]. The percent compositions of carbon, oxygen, silver, and nitrogen on the fabric surfaces are different, depending on the types of textile fibre [48]. The silver composition of 24.8% on the cotton fibre is higher than that of 23.4% on the nylon fibre and then is higher than that of 13.4% on the polyester fibre (see Supplementary materials: Figs. IB, D, F), while the size of AgNPs agglomerates appeared on the surface of cotton fibre is greater than that appeared on the surface of nylon fibre and then is greater than that appeared on the surface of polyester fibre (see Supplementary materials: Figs. IA, C, E). This means that the composition of silver on fabric surface may contribute to the size of AgNPs agglomerates.

The antibacterial properties of cotton, polyester, and nylon fabrics were verified against three bacteria of *E. coli*, *B. cereus*, and *C. haemolyticum* without and with changed fabric surface after binded AgNPs. The results (Supplementary materials: Fig. II; see Table 1) of inhibition zone show that the antibacterial activity of cotton, polyester, and nylon fabrics against *E. coli* is better than that against *C. haemolyticum* and then is better than that against *B. cereus*. Therefore, the diameters of inhibition zone that represent an effect of AgNPs on the *E. coli* growth are all greater than those on the *B. cereus* growth and then are greater than those on the *C. haemolyticum* growth on the fabric surfaces of cotton, polyester and nylon (see Table 1). The inhibition zone diameter of 6.33 ± 2.08 mm against Gram-negative bacteria *E. coli* [58] is greather than that of 5.67 ± 0.58 mm against Gram-negative bacteria *C. haemolyticum* [3] and then is greater than that of 2.00 ± 0.00 mm against Gram-positive bacteria *B. cereus* [5]. This may be due to Gram-positive bacteria have despite a lack of outer membrane but are surrounded by layers of peptidoglycan many times thicker than those found in Gram-negatives [50]. The layers of peptidoglycan help protect the bacterial cells of *B. cereus* from environmental stress of diffusing AgNPs and help preserve its cell morphology from the disturbance of AgNPs deposition. Antibacterial activity and acting mechanism of AgNPs against *E. coli* could be due to the deposition of AgNPs on the textile fabric surfaces can damage the structure of bacterial cell membrane and thus depress the activity of the membranous enzymes, which cause the *E. coli* bacteria to die eventually [28]. Since the activity of Gram-negative bacteria of *E. coli* and *C. haemolyticum* depends on an enzyme to metabolise oxygen to maintain their live, the deposition of AgNPs on fabric surface can interfere with the effectiveness of enzyme and disables the uptake of oxygen, which may cause the bacteria of *E. coli* and *C. haemolyticum* to die [52]. The adhesion of AgNPs to bacterial walls can penetrate the membrane and peptidoglycan layers of the Gram-negative bacteria of *E. coli* and *C. haemolyticum*. The bacterial cells can release antimicrobial Ag^+ ions from AgNPs inside the cells to interact with respiratory chain and to bind the thiol group of enzymes and amino acids [11, 30, 42, 51, 54]. The interaction of Ag^+ with thiol group of proteins and essential enzymes in the cellular respiratory chain can generate the reactive oxygen species. This may lead to the inactivation of the proteins. The process of extracting energy from the oxidation of organic compounds to produce CO_2 and H_2O doesn't occur in the Gram-negative bacteria of *E. coli* and *C. haemolyticum* [8, 24, 27].

4 Conclusions

This study proposed a new green method of using the pure leaf extract of *M. calabura* to bind AgNPs on the fabric surfaces of cotton, polyester, and nylon. The effect of interaction between *M. calabura* leaf extract and AgNPs on the property of fabric surface can alter the colour of AgNPs deposition from naturally lighter to darker colour. The deposition of AgNPs on fabric surface can reduce the water absorption leading to increase the density of textile fabric. The AgNPs deposition can modify the surface morphology of textile fabric by the formation of single particles and agglomerates of different sizes of the microparticles. The uniform distribution of AgNPs on polyester fabric surface achieves a good performance of structural reliability. The antibacterial property of the cotton, polyester, and nylon fabrics after binded AgNPs against Gram-negative bacteria of *E. coli* and *C. haemolyticum* could be better than Gram-positive bacteria *B. cereus*. The result findings of antibacterial effect of AgNPs deposition on the textile fabric surfaces contribute to many medical applications of the textile fabrics related to both Gram-positive and Gram-negative bacteria strains.

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Data availability The raw/processed data required to reproduce these findings cannot be shared at this time as the data also forms part of an ongoing study.

Compliance with ethical standards

Conflict of interest All the authors declare no conflict of interest.

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