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Original Article

Characterization and antibacterial activity of raw cotton fabrics treated with date seed extract and silver nanoparticles (AgNPs)

Caracterização e atividade antibacteriana de tecidos de algodão cru tratados com extrato de semente de tâmara e nanopartículas de prata (AgNPs)

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Abstract

Because of their immense economic, wellness, and remedial value, the seeds of palm (*Phoenix dactylifera)* were selected with synthesized silver nanoparticles (AgNPs) based on their properties for increasing the antibacterial efficacy of medical cotton. This study aimed to be contingent upon the characterisation of raw cotton fabrics treated by AgNPs with date seed extract (DSE) of *P. dactylifera* both individually and in combination and to investigate their antibacterial activity against various human pathogens. The prepared cotton materials with the synthesized AgNPs and/or DSE were described by both X-ray diffraction (XRD) and scanning electron microscope (SEM). At the same time, gas chromatography–mass spectrometry (GC-MS) and High-performance liquid chromatography (HPLC) were employed to determine the bioactive components in the aqueous date seed extract. The greater antibacterial activity was recorded by cotton treated with DSE and AgNPs mix, in which inhibition zones of all treatments were against *Escherichia coli* (8 cm), followed by *Staphylococcus aureus* (2.33-5.87cm) and *Bacillus subtilis* (2.17-4.63 cm), respectively. Overall, these findings indicate that treated cotton fabrics with synthesised AgNPs and DSE may be widely applied in various potential biological and medical applications, which could enhance environmental sustainability in closed production and consumption.

Keywords: date seed extract, cotton fabrics, silver nanoparticles, characterization, phenolics and flavonoids, antibacterial activity.

Resumo

Devido ao imenso valor econômico, propriedades curativas e de bem-estar, as sementes de palmeira (*Phoenix dactylifera*) foram selecionadas com nanopartículas de prata sintetizadas (AgNPs), com base em suas propriedades, visando aumentar a eficácia antibacteriana do algodão medicinal. Este estudo teve como objetivo a caracterização de tecidos de algodão cru tratados por AgNPs com extrato de semente de tâmara (DSE) de *P. dactylifera* tanto individualmente quanto em combinação e investigar sua atividade antibacteriana contra vários patógenos humanos. Os materiais de algodão preparados com os AgNPs sintetizados e/ou DSE foram descritos por difração de raios-X (XRD) e microscópio eletrônico de varredura (SEM). Ao mesmo tempo, cromatografia gasosa-espectrometria de massa (GC-MS) e cromatografia líquida de alta eficiência (HPLC) foram empregadas para determinar os componentes bioativos no extrato aquoso de sementes de tâmaras. A maior atividade antibacteriana foi registrada pelo algodão tratado com mistura de DSE e AgNPs, em que os halos de inibição de todos os tratamentos foram contra *Escherichia coli* (8 cm), seguido por *Staphylococcus aureus* (2,33-5,87 cm) e *Bacillus subtilis* (2,17-4,63 cm), respectivamente. De modo geral, essas descobertas indicam que os tecidos de algodão tratados com AgNPs sintetizados e DSE podem ser amplamente aplicados em várias aplicações biológicas e médicas potenciais, o que pode aumentar a sustentabilidade ambiental na produção e consumo fechados.

Palavras-chave: extrato de semente de tâmara, tecidos de algodão, nanopartículas de prata, caracterização, fenólicos e flavonóides, atividade antibacteriana.

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1. Introduction

Cotton represents the most desired fibers, which functions a major role in the agricultural, manufacturing, and medical importance. Cotton fabrics are exposed to microbial contamination and cellulose biodegradation that perform harmful health issues. Enveloping the cotton fabrics surface with nanoparticles is a trial for applying highly active surfaces as an antimicrobial (Saleem and Zaidi, 2020). Different metal nanoparticles might be synthesized on multiple fabrics using the method benefits of being clean, economically inexpensive, and easy to access (El-Naggar et al., 2018).

Silver nanoparticles (AgNPs) have gained an important interest as a result of their broad applications in chemistry, electronics, biomedicine, and other biotechnological approaches (Roy et al., 2019). The chemical structures on the particle surfaces, surface charge, and particle sizefundamentally affect the nanoparticle's behaviour (Mohammed et al., 2018). They also play a significant role in bio-pharmaceutical manufacturing, such as in the field of nanomedicine (Banu et al., 2018). Silver NPs have been conducted as topical antimicrobial agents for the therapy of various microbial skin infections (Gopinath et al., 2015). AgNPs may be synthesized by chemical, physical, biological, and mixed methods (Ansari and Alzohairy, 2018). Multiple physical and chemical ways were used to synthesize metal nanoparticles due to the agglomeration of NPs using surface passivators (Al-Awady et al., 2019). During fibers/fabrics adsorbed the metal ions to *in situ* reduction of these ions, the reduction increases the uniform dispersion of nanoparticles (Mowafi et al., 2017).

Covering the surface of targeted cotton fabrics with NPs is a strategy to produce extremely active surfaces with biological antimicrobial properties (El-Naggar et al., 2018). The synthesis of AgNPs by polyvinyl alcohol (PVA) was displayed as a simple method for nanometal particles. The raw fabrics were treated with nanoparticles at various concentrations ranged (50–3500 ppm) at room temperature. The treated fabrics microbial growth (Gram +ve and Gram -ve bacteria) (Yazdanshenas and Shateri-Khalilabad, 2013). Moreover, their prevailing property is their maximum antibacterial action against a wide range of harmful bacteria lacking any toxicity to animal cells (Elshawy et al., 2016).

Medicinal plant metabolites are used for treating many diseases as they are cost-effective and widely applicable. *Phoenix dactylifera* (date palm) is a significant and main economic crops and food of the Arabian community, including the Kingdom of Saudi Arabia (Alananbeh et al., 2014). Date seeds are the main waste fabrics that comprise approximately 6.1–11.5% of the fruits (Habib and Ibrahim, 2009). Include a big amount of essential nutritional molecules such as sugars, fatty acids, fibers, protein, vitamins, and minerals (Al-Farsi et al., 2007). Date seeds have an antioxidant effect as they incorporate high quantities of flavonoids (Bouhlali et al., 2017), phenolics, anthraquinones, and tannins (Adeosun et al., 2016). The date seeds extracts reported moderate antibacterial activities against *Staphylococcus aureus, Bacillus cereus*, *Enterococcus faecalis, Methicillin-resistant Staphylococcus aureus* (MRSA), *Escherichia coli,* and *Pseudomonas aeruginosa* (Bentrad et al., 2017). This study aimed to support the green economy and sustainable development by formulating methods for recycling date seeds and creating environmentally friendly economic value through the treatment of cotton fibers with AgNPs, DSE, and a mixture of AgNPs and DSE. Then, we evaluated the antibacterial actions of the treated cotton materials.

2. Materials and Methods

2.1. Materials

Absorbent medical cotton fabric (500 g) was supplied by Misr Company for Spinning and Weaving (El-Mahalla El-Kubra, Egypt). Dried dates were collected from Riyadh,the type it Khahas from farm in Al-Ahsa Governorate,Saudi Arabia. Silver nitrate (AgNO3), polyvinylpyrrolidone (PVP), trisodium 2-hydroxypropane-1,2,3-tricarboxylate hydrate (Na3Ct), dimethylaminoethanol (DMAE), sodium hydroxide (NaOH) and acetic acid were obtained from chemicals companies at Saudi Arabia, The bacterial were obtained and identified from Department of Botany and Microbiology, College of Sciences, King Saud University, Riyadh, Saudi Arabia

2.2. Methods

2.2.1. Preparation of date seeds powder and extract

Clean and dry seeds of selected date were ground (the average size of the seed before grinding 0.5-0.9 gm) using a heavy-duty mill. Two grams of date seeds powder were soaked in 250 ml distilled H_2O followed by stirring for 6 h, then filtered using filter paper and kept in the refrigerator.

2.3. Preparation of AgNPs

AgNPs were prepared based on the method adopted by (Natsuki and Abe, 2011). 1.0 g PVP was liquified in 20 ml deionized H_2O by stirring for 10 min at room temperature. 0.5 g of $AgNO_3$ was added and the solution was stirred at the same time. An aqueous solution of Na_3Ct (0.88 g) in 20 ml deionized H_2O was added dropwise using a micro-pump. After that, the DMAE solution (0.027 g) in 0.5 ml deionized H_2O was added to the reaction mixture and stirred for 60 min. White to pale brown color of the solution being gradually changed. The AgNPs were separated from the solution by centrifugation at 5000 rpm, then washed twice and re-dispersed in 10 ml deionized water.

2.4. Treatment of cotton fabrics

A 18% w/w NaOH solution was used to mercerize the tested cotton fabrics for 15 min followed by washing and neutralizing with 2% of acetic acid and drying at 70 °C.
A-Treatment of cotton fabrics with DSE

The cotton fabrics samples were immersed in DSE suspension followed by padding the wet fabrics as a consequence of 2 dips and 2 nips with 1.5 kg/cm^2 pressure using an automatic padder and dried for 3 min at 80 °C.

After drying, the cotton fabric was treated for 2 min at 140 °C as previously described by (El-Naggar et al., 2018).
B-Treatment of cotton fabrics with AgNPs

The cotton fabrics samples were submerged in AgNPs suspension followed by padding the wet fabrics.
C-Treatment of cotton fabrics with AgNPs /DSE

The pre-treated fabrics with step A were immersed in AgNPs suspension and then followed by padding the wet fabrics.

2.5. Characterization of tested cotton fabrics by X-ray diffraction (XRD)

The XRD diffraction patterns of the treated cotton samples were recorded at room temperature (22± 2 °C) in a step scanning mode using a powder X-ray diffractometer (Panalytical X'PERT PRO) with Cu kα- radiation (λ = 1. 5406 Å), operated at 30 mA and 45 kV. The powdered diffraction patterns were adhered in the cubes of XRD, scanned at 2θ angle, in the range of 5 to 80º, with scan action at 0.026, with a numeration time 20 sec/step. The diffraction peaks were compared with those on standard database files (JCPDS card No. 04-0783) to demonstrate the transparent nature, and the results was then taken in the XRD equipment. Energy dispersive X-ray (EDX) analysis was also used to determine the elements detected on the surface of date seed powder.

2.6. Characterization of treated cotton fabrics by SEM

Microscopic investigations on date seed powder and cotton fabrics samples were performed using a Philips XL30 SEM equipped with a LaB6 electron gun. The obtained images were studied at various magnifications ranged from 1509 to 30009.

2.7. Gas chromatography-mass spectroscopy (GC-MS) and high-performance liquid chromatography (HPLC) analysis of date seed extract

The obtained aqueous extract was analyzed by using Trace GC Ultra-ISQ mass spectrometer (Thermo Scientific, Austin, TX, USA), and the compounds were separated on 30 m x 0.25 mm x 0.25 µm film thickness TG–5MS capillary column as described previously (Al Mousa et al., 2021). While, HPLC (Agilent 1100, USA) with automatic injection, equipped with a quaternary gradient pump, in-line degasser, dual wavelength UV/Vis detector and chromatographic separations were performed on a C18 column (25 x 0.4 cm, particle size 5 mm) according to (Movahhedin et al., 2016).

2.8. Antibacterial activity

Test microorganisms including *Staphylococcus aureus, Bacillus subtilis* and *Escherichia coli* were obtained from King Saud University, College of Science, Department of Botany and Microbiology, Saudi Arabia. The antibacterial activity of fabric samples was evaluated against bacteria using the disc diffusion method on nutrient agar plates pH 7.2 inoculated with spore suspension 10^5 CFU of each tested bacteria at various inoculum sizes (0.5, 1, and 1.5 mL). Treated cotton fabrics A, B and C were cut into squares of 1.3 cm, and then planted onto the solid agar plates. All the cultivated plates were incubated for 24 h at 37 ºC and investigated for the formation of a zone of inhibition-surrounded samples. All tests were performed in triplicates (Ramadan et al., 2020).

2.9. Statistical analysis

Each experiment in this study was carried out in triplicate, and all experimental data from each experiment were statistically assessed by mean±SD for all groups (n = 3).

3. Results and Discussion

Based on the resistance profile of various antibiotic for multiple human pathogenic bacteria, which is seemly a serious problem, the use of wide-ranging antibiotics to control it is less effective, more toxic, and highly expensive (Asma et al., 2019). So, the scientists are more partial with AgNPs, as there is much indication suggesting that using Ag+ in the form AgNPs improves the antimicrobial activity properly (Qing et al., 2018). Moreover, multiple reports indicated the significance of AgNPs in improving the antibacterial effects (Asma et al., 2019; Kim et al., 2016; Efavi et al., 2022). In this study, DSE and AgNPs were prepared and used for the treatment of cotton fabrics both individually or mixed to evaluate their antibacterial activity to improve the efficacy of cotton fabrics to minimize microbial infections. Additionally, treated cotton fabrics as well as DSE were characterized to indicate the efficiency of the utilized treatments. Figure 1A-1B illustrated the DSE preparation and different cotton fabrics treatments. The obtained colour observation was contingent on the excitation of plasmon vibration surfaces and serve as an indicator of AgNPs synthesis. The absorbance colour has changed due to the DSE, which may be ascribed to the existence of various capping and reducing agents in the extracts and the existence of phenolics and flavonoid components (Al-Farsi and Lee, 2008).

3.1. Characterization of treated cotton fabrics

The structural properties of the treated cotton fabrics with silver nanoparticles compared to that treated with date seed extract were analysed using the XRD technique (Figure 2). The XRD pattern showed data which can be indexed corresponding to the reflections from the (111, 200, 220, and 311) planes. These planes corresponded to fcc Ag and revealed the crystalline nature of the AgNPs. The crystalline nature of the formed AgNPs was also further confirmed by XRD analysis. The XRD pattern also revealed the structural properties of treated fabrics with the mix between silver and DSE recorded on the same angles of AgNPs spectrum confirms the successful coating of fabrics with AgNPs. In the same context, the diffraction spectrum of the date seed powder is illustrated in Figure 3. The presence of the important amount of zirconium (Zr) element beside some trace elements such as potassium (K) and sulphur (S) on the cotton-treated fabrics can be observed. These compounds were the major constituents of cotton and date seeds.

Figure 1. (A) Formation of DSE, (B) preparation of treated cotton fabrics.

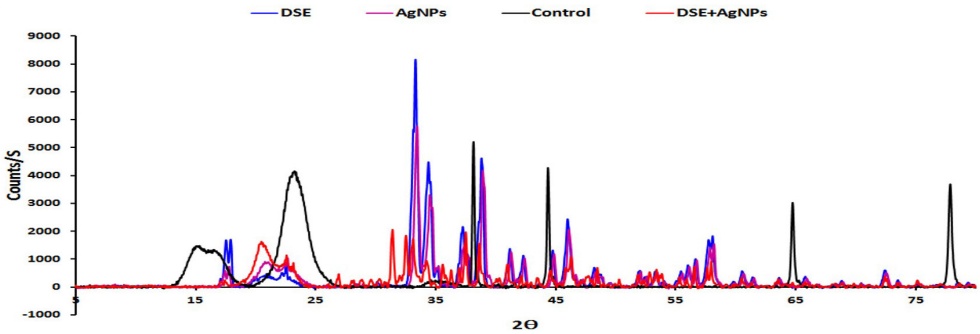

Figure 2. XRD patterns of the cotton fabrics treated with DSE, AgNPs and the mix between both.

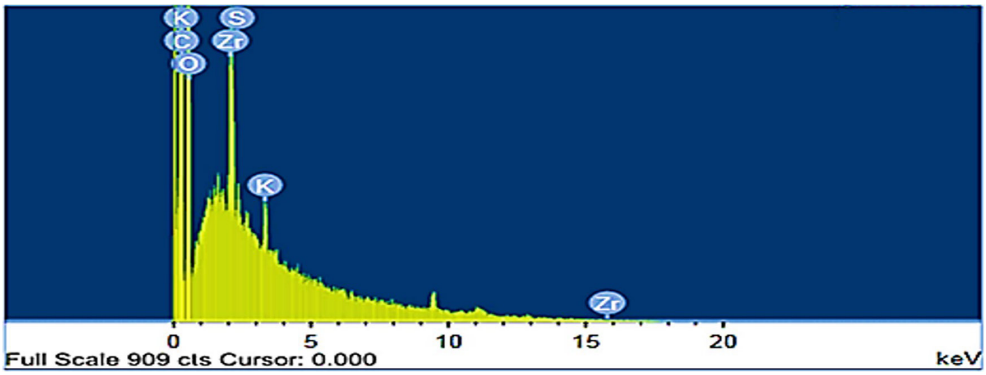

Figure 3. EDX diffraction spectra of the date seeds powder.

The surface morphology of the treated cotton fabrics treated with the DSE capped silver nanoparticles was studied by SEM taken at low magnification and illustrated in Figure 4 to determine the shape of particles and their distribution. The SEM imageindicates that the cotton fabrics treated with silver nanoparticles are covered with the DSE as a thin film. The absence of silver elements in the SEM or XRD spectrum may be related to the relatively low intensity of silver particles used. This may be attributed to the concentration of the silver particles in the colloidal solution used (Lee et al., 2003; Ki et al., 2007).

3.2. Antibacterial activity

The antibacterial potential of cotton fabric samples supplemented with DSE and AgNPs was examined against human pathogenic bacteria using the agar plate diffusion method (Figure 5). The data given in Table 1 revealed that the presence of AgNPs enhanced microbial activity,

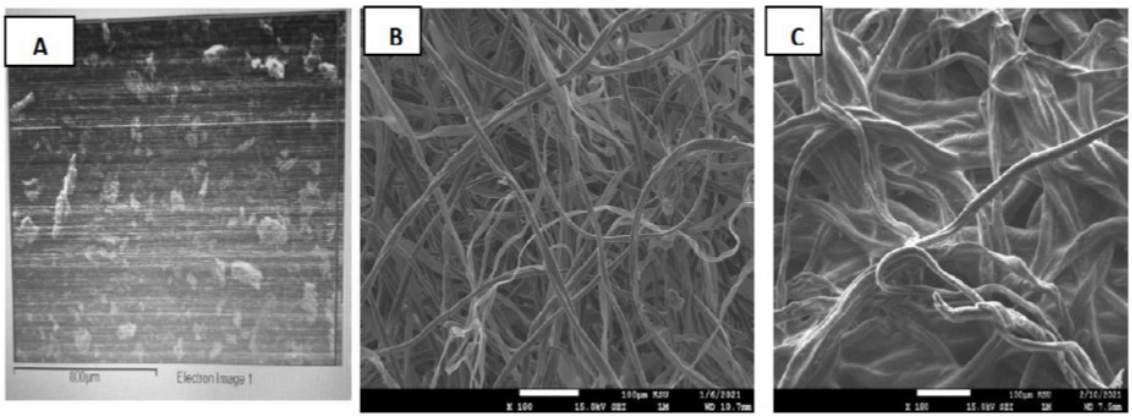

Figure 4. Showing scanning electron microscope of (A) date seed powder, (B) control cotton fabrics, (C) cotton fabrics treated with DSE capped AgNPs.

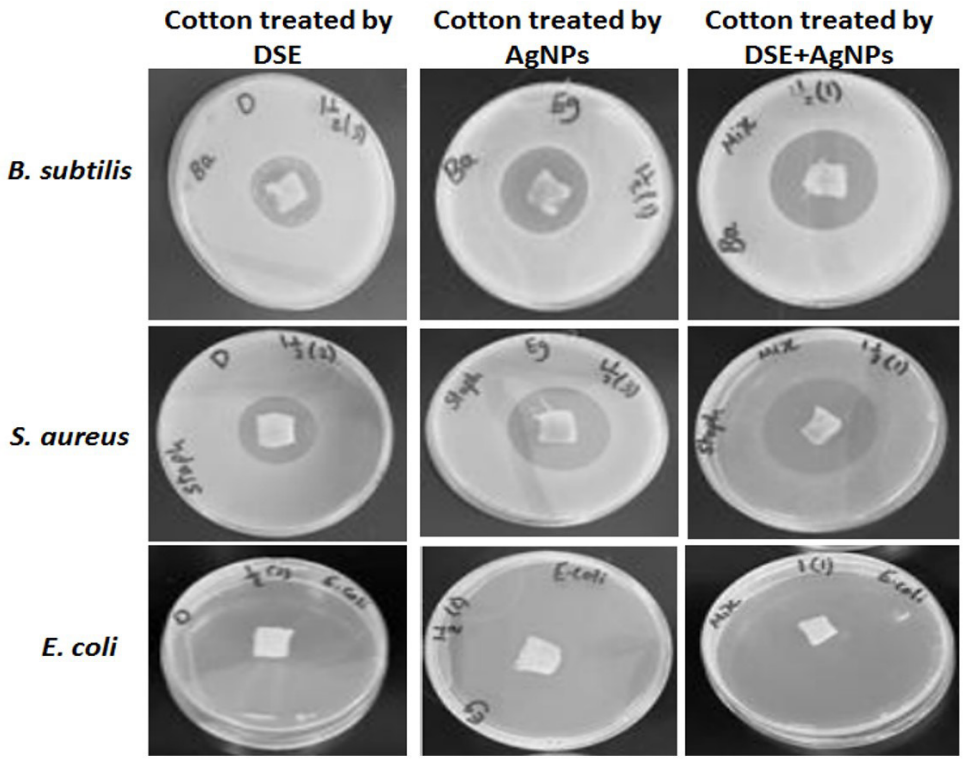

Figure 5. The antibacterial activity of cotton fabrics treated with DSE, AgNPs, and mix (DSE+AgNPs) against tested pathogenic bacteria.

Table 1. The antibacterial activity of cotton fabrics saturated with DSE, AgNPs as well as mix (DSE+AgNPs) against pathogenic bacteria.

Treatment	Inoculum size	Inhibition zone diameter (cm)		
		B. subtilis	***S. aureus***	***E. coli***
DSE	0.5 mL	3.77±0.21	5.03±0.13	8.00±0.00
	1 mL	3.73±0.33	3.77±0.21	8.00±0.00
	1.5 mL	2.17±0.05	2.33±0.13	8.00±0.00
AgNPs	0.5 mL	4.40±0.29	4.53±0.21	8.00±0.00
	1 mL	4.10±0.13	4.07±0.12	8.00±0.00
	1.5 mL	3.23±0.25	2.90±0.08	8.00±0.00
Mix (DSE +AgNPs)	0.5 mL	4.90±0.08	5.87±0.05	8.00±0.00
	1 mL	4.63±0.33	4.53±0.05	8.00±0.00
	1.5 mL	3.90±0.08	4.06±0.19	8.00±0.00
Control		-	-	-

(-) = not detected.

suppressing the growth of pathogenic bacteria, regardless of the individual added. Notably, all cotton treatments at different inoculum sizes completely suppress the growth of *E. coli*. The highest antibacterial actions clearly appeared at 0.5 mL of bacterial concentration in fabrics supplemented with mixed DSE+AgNPs against *B. subtilis,* and *S. aureus* (4.9 and 5.87 cm), respectively. At a high concentration of bacterial cells (1.5 mL), antibacterial inhibition was decreased. Study by Ansari and Alzohairy (2018) determined that the antibacterial activities of AgNPs were increased at higher concentrations, and the inhibition zones were found to range from (11 to 24 mm), at a concentration of (7.8 to 500 µg/mL). Our results agree with earlier work that investigates the antibacterial activity of AgNPs using extracts of various plant parts (Das et al., 2017). As with our results, the antibacterial activity of DSE-treated and non-treated ZnONPs were examined against *S aureus* and *E. coli,* showing that the reduction rate of DSE against *E. coli* was very low (26%) while the reduction rates of the treated and non-treated ZnONPs against *S. aureus* and *E. coli.* were 99 and 85%, respectively (El-Naggar et al., 2018).

Nanoparticles have been used in clothing to limit bacterial growth (Vigneshwaran et al., 2007). Silver nanoparticles have been examined for their ability to reduce microbial infections in skin and burn wounds (Ulkür et al., 2005; Paddle-Ledinek et al., 2006). Silver has been used extensively in topical preparations and to saturate bandages to restrict bacterial growth in injured skin (Nomiya et al., 2004). Mechanisms have been proposed for the antibacterial efficacy of silver nanoparticles includes adhesion to cell wall and altering the membrane properties by degrading lipopolysaccharides, accumulating inside the membrane and thus causing increases in membrane permeability. In addition, penetration of AgNPs inside cells, causes DNA damage (Sondi and Salopek-Sondi, 2004). Moreover, dissolution of AgNPs releases silver ions which interact with thiol groups in cysteine residues of proteins, resulting in inactivation of respiratory enzymes and producing harmful reactive oxygen species (Matsumura et al., 2003; Morones et al., 2005). Also, Ag ions prevent DNA replication and affect the structure and permeability of the cell membrane (Feng et al., 2000).

3.3. Identification of bioactive compounds of DSE by GC-MS and HPLC

In our study, we analyzed the chemical composition of the DSE by GC-MS, finding the presence of various compounds with different concentrations. In total, 24 chemical compounds were identified; the peak area of each compound is directly proportional to its quantity in the extract. Based on abundance constituents, the top major compounds found in the DSE were 1-Dodecanamine, N,N-dimethyl- (37.5%), 1-Tetradecanamine, N,N-dimethyl- (12.91%), Benzene, ((1-pentylheptyl)- (9.19%), Benzyl chloride (8.09%). Benzene, (1-pentyloctyl)- (6.18%), Benzene, (1-butylheptyl)- (3.92%), 9-Octadecenoic acid (Z)-, methyl ester (2.40%). Other compounds found at a percentage less than 2% were Benzene, (1-ethyldecyl)- ((2.34%), Benzene, (1-propylnonyl)- (2.18%), Benzene, and (1-methylundecyl)- (2.13%), respectively. All these identified compounds are known; their elution times, molecular formulae, and GC-MS profile information were summarized in Table 2 and Figure 6.

Several active compounds of medicinal plants have shown interesting pharmacological actions, such as antimicrobial, anticancer, and antioxidant properties (Malongane et al., 2017; Anand et al., 2019). The potential of these active compounds from plants that contain complex mixtures of various phytochemicals should be assessed and analysed for their application in the treatment of various diseases (Pandey et al., 2008; Konappa et al., 2020). Similar to our study, *n*-hexane extract of *P. dactylifera* seeds and leaves was analyzed through capillary GC-MS, and the compounds were identified by comparison of GC-MS spectrum with library searches indicating forty-one compounds were identified including the fatty acid methyl esters as the major detected components (Azmat et al., 2010). The phytochemical composition of *P. dactylifera* with different solvent fractions was analyzed, and multiple active compounds were determined (Obode et al., 2020).

Table 2. GC-MS analysis of biologically active chemical compounds with synonyms of DSE.

No.	Compounds	Chemical formula	MW	RT (min)	Match Factor	Area (%)
1	Heptanoic acid, 2,2-dimethyl-6-oxo-, methyl ester	$C_{10}H_{18}O_3$	186	4.36	624	0.96
2	Benzyl chloride	C_7H_7Cl	126	4.95	968	8.09
3	1-Dodecanamine, N,N-dimethyl-*Syn. (Dimethyl lauramine)	$C_{14}H_{31}N$	213	15.13	937	37.50
4	Benzene, (1-butylhexyl)- Syn. (5-Phenyldecane)	$C_{16}H_{26}$	218	15.86	889	0.70
5	Benzene, (1-propylheptyl)- Syn. (4-Phenyldecane)	$C_{16}H_{26}$	218	16.10	894	0.45
6	Benzene, (1-ethyloctyl)- Syn. (Decane, 3-phenyl-)	$C_{16}H_{26}$	218	16.53	847	0.59
7	Benzene, (1-methylnonyl)- Syn. Undecane, 2-phenyl-	$C_{16}H_{26}$	218	17.43	913	0.52
8	Benzene, (1-butylheptyl)- Syn. 5-Phenyldecane	$C_{17}H_{28}$	232	18.13	904	3.92
9	Benzene, (1-propyloctyl)- Syn. 4-Phenylundecane	$C_{17}H_{28}$	232	18.38	905	1.45
10	Benzene, (1-ethylnonyl)- Syn. 3-Phenylundecane	$C_{17}H_{28}$	232	18.85	889	1.72
11	1-Tetradecanamine, N,N-dimethyl- Syn. Myristamine oxide	$C_{16}H_{35}N$	241	19.69	924	12.91
12	Benzene, (1-pentylheptyl)- Syn. Dodecane, 6-phenyl-	$C_{18}H_{30}$	246	20.31	898	9.19
13	Benzene, (1-propylnonyl)- Syn. Dodecane, 3-phenyl-	$C_{18}H_{30}$	246	20.62	911	2.18
14	Benzene, (1-ethyldecyl)- Syn. Dodecane, 3-phenyl-	$C_{18}H_{30}$	246	21.09	900	2.34
15	Benzene, (1-methylundecyl)- Syn. Dodecane, 2-phenyl-	$C_{18}H_{30}$	246	21.97	898	2.13
16	Benzene, (1-pentyloctyl)- Syn. 6-Phenyltridecane	$C_{19}H_{32}$	260	22.34	877	6.18
17	Benzene, (1-propylundecyl)- Syn. Tridecane, 4-phenyl-	$C_{19}H_{32}$	260	22.76	852	1.12
18	Benzene, (1-ethylundecyl)- Syn. Tridecane, 3-phenyl-	$C_{19}H_{32}$	260	23.25	869	1.15
19	Benzene, (1-methyldodecyl)- Syn. 2-Phenyltridecane	$C_{19}H_{32}$	260	24.09	880	0.86
20	Hexadecanoic acid, methyl ester Syn. Palmitic acid methyl ester	$C_{17}H_{34}O_2$	270	24.40	843	0.61
21	9-Octadecenoic acid (Z)-, methyl ester Syn. Oleic acid, methyl ester	$C_{19}H_{36}O_2$	296	27.76	939	2.40
22	2-Methylenebrexane	$C_{10}H_{14}$	134	28.09	918	1.81
23	9-Octadecenoic acid, (E)- Syn. Elaidic acid	$C_{18}H_{34}O_2$	282	29.59	895	0.80
24	Fumaric acid, myrtenyl octyl ester	$C_{22}H_{34}O_4$	362	31.74	719	0.43

MW = molecular weight; RT = Retention Time; Syn. = synonym of the identified compound(s).

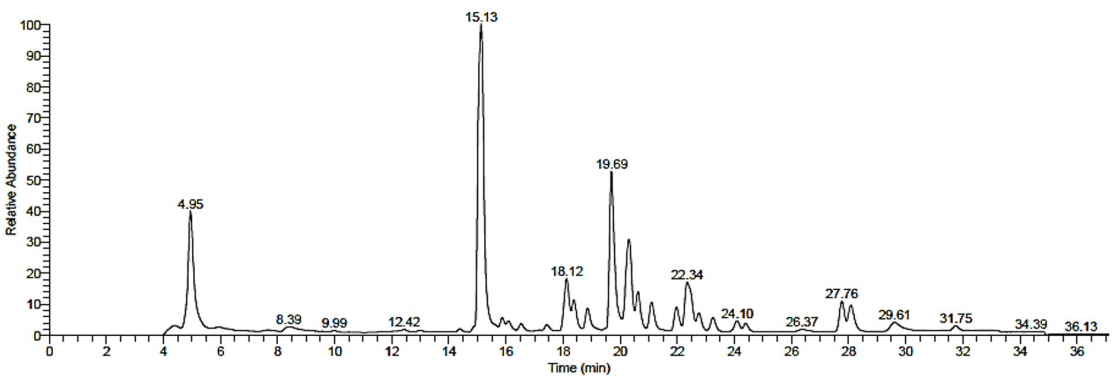

Figure 6. A typical GC-MS chromatogram of the bioactive compounds present in DSE.

The identification and quantification of individual phenolic compounds from the seed extract of *P. dactylifera* were performed via HPLC analysis. The results show that the phenolic compounds included syringic acid, chlorogenic acid, caffeic acid, pyrogallol, and protocatechuic acid. As the data presented in Figure 7 show, there were three major phenolic compounds (caffeic acid, pyrogallol, and chlorogenic acid) in DSE at concentrations of approximately

19.46, 13.04, and 10.69 µg/g, respectively. Syringic acid had the lowest concentration among other phenolic compounds, reaching up to 6.14 µg/g. The HPLC spectra are illustrated in Figure 7A, while the identities and contents of the phenolic compounds are listed in Table 3. Similarly, the flavonoid content in DSE showed that rutin, 7-hydroxyflavone, myricetin, quercetin, and hesperidin are the primary compounds Figure 7B. The maximum and minimum yields were observed in hesperidin and quercetin at concentrations of 14.63 and 13.22 µg/g, respectively. On the other hand, 7-Hydroxyflavone was determined to have the lowest flavonoid content, at 4.2 µg/g (Table 3).

The HPLC is a universally used chromatographic technique for quantitative and qualitative analyses of various phytochemicals, primarily phenolics and flavonoid compounds. It is also considered the best technique based on its high resolution and sensitivity compared to classical and traditional methods (Plazonić et al., 2009). The natural products of medicinal plants are widely employed as a precious and useful treatment against a variety of severe illnesses. In this context, *P. dactylifera* is one of the most critical and major economic food and crops of the Middle East (Ansari and Alzohairy, 2018). Another study by Al-Orf et al. (2012) reported the presence of flavonoids, phenols, carotenoids as well as anthocyanins in date fruits. Biological activities reported for phenolic compounds include antioxidant, free radical scavenging, antimicrobial, anti-inflammatory, as well as anti-carcinogenic effects (Baliga et al., 2011). Thus, it could be inferred that the presence of phenolics and flavonoids in *P. dactylifera*, could mitigate some of the risk diseases associated with microbial infection.

Plant phenolics, secondary metabolites consisting of polyhydroxy phytochemicals, considered a source of

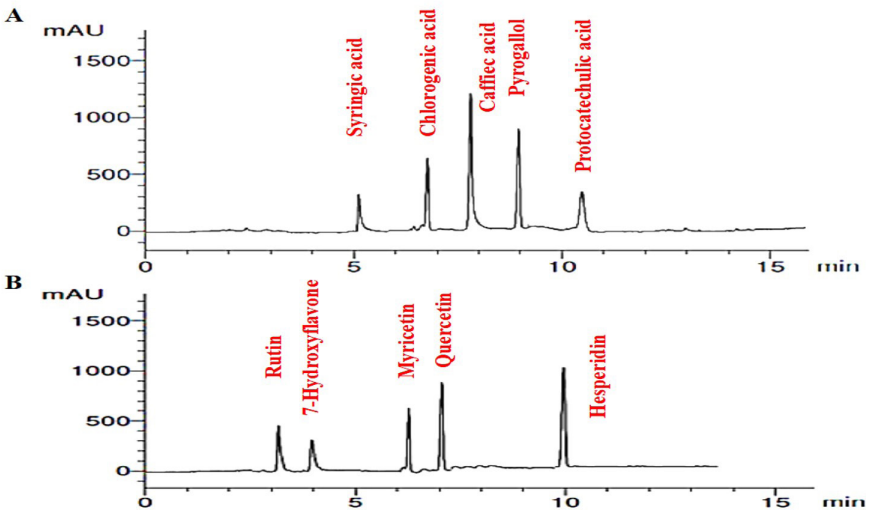

Figure 7. HPLC chromatogram of phenolics (A), and flavonoids (B) components of DSE.

Table 3. HPLC analysis for phenolics and flavonoids components of DSE.

Type	Peak	Compound	Retention Time (min)	Concentration (µg/gm)
Phenolics	1	Syringic acid	5.1	6.14
	2	Chlorogenic acid	7.0	10.69
	3	Caffiec acid	8.0	19.46
	4	Pyrogallol	9.0	13.04
	5	Protocatechulic acid	10.3	6.33
Flavonoids	1	Rutin	3.0	7.11
	2	7-Hydroxyflavone	4.0	4.23
	3	Myricetin	6.0	10.71
	4	Quercetin	7.0	13.22
	5	Hesperidin	10.0	14.63

novel anti-infective agents against antibiotic-resistant human pathogens (Ferrazzano et al., 2011). Phenolic acids exhibit antimicrobial potentials that have been studied through the chemical structure, especially by saturated chain length, position, and number of substitutions in the core benzene ring (Cueva et al., 2010). Pholyphenols act on different bacterial strains, including *E. coli*, *S. marcescens*, *K. pneumoniae*, *P. aeruginosa*, *S. aureus*, and *B. subtilis* by generating toxic hydrogen peroxide and altering the permeability of the bacterial membrane (Hattori et al., 1990; Haslam et al., 1992), as well as disrupting biosynthetic proteins involved in protein synthesis, and phospholipid, carbon, and energy metabolism (Hu et al., 2010). Furthermore, polyphenols have been reported to interfere with bacterial quorum sensing (Huber et al., 2003). Several flavonoids have been shown to possess a potent antibacterial activity based on their molecular actions to form a complex with proteins through nonspecific forces, thus disrupting bacterial cell membranes (Kumar and Pandey, 2013).

4. Conclusions

In this study, an aqueous seed extract of *P. dactylifera* was prepared and AgNPs were synthesized to treat raw cotton fabrics with DSE and/or AgNPs to improve these fabrics' performance and antibacterial properties. Moreover, treated cotton fabrics were characterised via XRD and SEM to study their chemical and morphological features. In addition, aqueous DSE was proposed based on an analysis of its active compounds identified with the help of GC-MS and HPLC techniques. Our results indicated that AgNPs and DSE loading efficiency enhanced the antibacterial properties of treated cotton fabrics against human pathogenic bacteria. research on the biological activity of treated cotton fabrics with DSE and AgNPs is needed to study the relevant mechanisms and biochemical actions. Additionally, our study suggests that AgNPs combined with DSE may constitute an alternative method for the treatment of biologically and medically associated infections and serving other industrial applications to promote environmental sustainability in closed production and consumption.

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