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Assessment of The Antimicrobial Activities of Trioctylphosphine Oxide Modified Silica Nanoparticles

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SILICA nanoparticles (SNPs) are particles of silica which are in the range of 1 to 100 nm in size. In the present study, native silica nanoparticles (SNPs) have been prepared chemically using cetyltrimethyl ammonium bromide (CTAB) and sodium silicate as precursors. The prepared native SNPs were organically modified using the trioctylphosphine oxide (Cyanex921) to yield the modified CY-SNPs particles. The synthesized SNPs and CY-SNPs were characterized by using Scanning Electron Microscope (SEM) micrographs that showed spherical particles with an average size of 35 nm. The elemental analysis was performed using the Energy Dispersive Spectrum (EDS). For the native SNPs, The peaks recorded around 1.9 Kv and 0.5 Kv are the binding energies corresponding to Si and O, respectively. For the modified CY-SNPs, an additional peak around 2.1 Kv corresponding to phosphorous from the cyanex921 moiety was observed. The powder X-Ray Diffraction (XRD) analysis of the material further confirmed the crystallinity of the SNPs as evidenced by the diffraction pattern at broad peak centered at 2Θ=20o which indicates that the sample is amorphous. Fourier Transform Infra -Red Spectroscopy (FTIR) spectra indicated the loading of cyanex921 to the surface of the native SNPs. The antimicrobial activities of native and phosphine modified SNPs were assessed against Gram-positive and Gram-negative microorganisms using the minimum inhibitory concentration (MIC) studies. The results obtained showed that CY-SNPs have potential antibacterial effects against the gram positive microorganisms, viz. methicillin resistant staphylococcus aureus (MRSA) and the gram negative microorganisms viz. E.coli, klebsiella. Sp. and pseudomonas sp. and the MIC corresponding to each type has been determined. The native silica nanoparticles have not shown any antibacterial effect against the four bacteria strains previously mentioned over concentrations 0.10-5.0 mg/mL. The mechanism of the antibacterial activity of the proposed phosphine modified silica nanoparticles was discussed. The present study can generally approve the qualification of caynex921modified silica nanoparticles for the use as antibacterial agents.

Keywords: Silica nanoparticles, trioctylphosphine oxide, antibacterial activities, SEM, EDS, XRD, FTIR

Introduction

Nanotechnology is our gate to a completely different world, as a result of many and diverse applications in all areas of science. Microbiology is not far from advantaging from the treasures of nanotechnology. Such combination between these two science results in many antimicrobial nanomaterials.

Widespread and increasing antibiotic resistance has become a critical problem for healthcare [1,

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2]. Organic natural products, which have provided the core set of current therapeutics, have been central to our ability to control these multi-drug resistant pathogens; however, microbes have been harnessing antibiotics for competition for billions of years, and as a result, mechanisms for resisting and tolerating antibiotics have been evolving for just as long [3,4]. For each new antimicrobial natural product discovered, at least one mechanism of resistance is already present in the general environment, greatly accelerating the emergence of antibiotic resistance [5]. One possible strategy for overcoming these obstacles and regaining some ground on the antibiotic resistance problem is to develop synthetic antimicrobials whose chemical architectures do not occur naturally, and would thus be evolutionarily foreign to bacteria. In addition, if such antimicrobials degraded rapidly in the general environment, strong selective pressure for the evolution of resistance would be reduced significantly. Organophosphorus compounds remain an untapped pool of chemical architectures that could possess novel chemistries and differential binding affinities to diverse microbiological targets. Also, because phosphorus has a similar electronegativity to carbon, the chemistry of low valent phosphorus often resembles that of carbon, making it highly amenable for syntheses of compounds for biological applications [6]. Phosphorus-containing antibiotics have been synthesized previously [7-9]; however, these molecules are organophosphates that may be susceptible to existing antibiotic resistance mechanisms. In contrast to organophosphates, phosphine derivatives remain underexplored as potential antimicrobials [10, 11]. These compounds provide a large pool of potentially biologically active molecules with vast structural diversity, mainly due to the ease with which they can be modified chemically [12]. Phosphines also provide a simple means of introducing metal complexes into biologically active molecules, via coordination of the lone pair, further expanding the range of inorganic groups that can be explored. Phosphine derivatives have been shown to have potential as anti-cancer drugs [11], and even to have potential as antibiotics [8]. Phosphorus-containing functional groups could yield compounds with unique biochemistry, such as stronger binding affinity to certain enzymes as compared to carbon or nitrogen analogs. Non-phosphate, organophosphorus compounds therefore have enormous capacity to provide new chemical architectures for the development of next-generation antibiotics.

The antibacterial nanomaterials, such as nano metal oxides, have offered some kind of cure to this problem [13]. Therefore, nanoparticles have the potential to act as an alternative to antibiotics and to control infections caused by microbes such as MRSA [14].

The biomedical applications of silica nanoparticles are diverse and have been abundantly reported. This includes their use in the form of antibiotic-delivering biological dressings by embedding antibiotics within silica that control their release from the host matrix into the surrounding medium [15]. Besides the applications as gene delivery [16], pest control [17], and antibacterial textiles [18, 19], recent researches reveal also the antiviral efficacy of silica NPs [20].

As has been excessively reported, the antimicrobial role of native silica nanoparticles and its diverse modified forms were a recent subject of attraction. Silver nanoparticles, aminoglycoside, gold nanoparticles, copper nanoparticles and nitric oxide were among the most studied modifiers for silica nanoparticles and the antimicrobial efficacy for their nanosilica composites has been established [21-25]. The review, published by Camporotondi et.al [26], reveals that silica based nanostructured materials are promising as antibacterial agents according to his gathered results from literature. A literature survey reveals that studies on the antimicrobial activities of phosphine derivatives are rarely reported [27, 28]. In this regards, to the best of our knowledge, the antimicrobial activities of trioctylphosphine oxide modified silica nanoparticles have not been reported in the literature.

Hence the present study was carried out to help investigating the potential antimicrobial role of the native silica nanoparticles and trioctylphosphine oxide modified forms. The preparation of spherical silica nanoparticles was done by modifying the method used by Mohammad Teymouri et.al [29]. A CTAP surfactant and sodium silicate were the precursors for the synthesizing process. The preparation was followed by functionalizing the resulted nanoparticles by trioctylphosphine oxide (cyanex921) The prepared nanoparticles were subjected to characterization through SEM, XRD, EDS, FTIR techniques in order to determine their

chemical and physical properties.

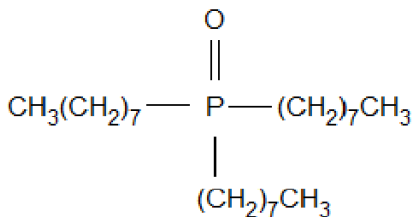
The antimicrobial activity of the native SNPs and the modified CY-SNPs were assessed against Gram-positive and Gram-negative bacteria using the minimum inhibitory concentration (MIC) studies. More than one organism was tested to increase the chance of detecting antibacterial activities. The MIC is the lowest concentration of an antibacterial agent that inhibits the visible growth of bacteria. A group of serial concentrations of well dispersed native and modified SNPs in nutrient broth media was used for culturing the bacterial strains under study to help the direct contact between both the silica NPs and bacterial cells. The growth of bacteria was noticed visually after incubation for 24 hours at 37°C and the results have been reported.

Experimental

Materials

For preparation of nanoparticles the following chemicals have been used; cetyl trimethyl ammonium bromide (CTAB 99%), from Win lab, UK, sodium silicate solution ((28 wt.% SiO_2, 5 wt.% Na_2O, 67 wt.%, H_2O), from Sigma-Aldrich, dehydrated ethanol (99.9%) from International Co. for Supp. and Med. Industries, $CYANEX_{921}$ (scheme 1) from Cyanamid, tetraeth(amino propyl) silane and xylone. All chemicals were used as purchased and no further purification was performed.

For antibacterial studies, Bacterial isolates of *E.coli, Klebsiella sp, MRSA, Pseudomonas sp.* were kindly provided and identified by Microbiology Lab., Gastroenterology Surgical Center - Mansoura University. Nutrient broth powder, from Oxide, England was used as cultivating media.



Scheme 1: Trioctylphosphine oxide (Cynex921)

Instrumentation

For characterization of the prepared nanoparticles, the following devices have been used; Scanning electron microscopy (SEM, JEOL, JSM-6510 lv, Japan), Fourier transmission infrared spectroscopy (FT-IR, Shimadzu, 8400s, Japan), Energy dispersive spectroscopy (EDS, Oxford X-Max 20), X-Ray Diffraction (XRD, XRD 7000, Shimadzu, Japan), Zeta Potential Analyzer (Malvern Zeta size Nano-zs90) , (TGA-50 SHIMADZU / DTA-50 SHIMADZU, Japan).

For antibacterial studies, Laminar flow hood (Holtan lamin air HB2448) and incubator (Heraeus B6420) were the instrumental devices used.

Procedures

Preparation

-Preparation of silica nanoparticles

Cetyltrimethylammonium bromide (CTAB) surfactant solution was prepared by adding 2.6g of CTAB to 69g of double distilled water with continuous stirring to give a clear solution. To this solution, 8.2g of ethanol was added with continuous stirring. 9.3g of an aqueous solution of sodium silicate was added to surfactant solution, stirred for an hour, the solution was left for two hours for phase separation. To the bottom phase ethanol was added to yield white precipitate, this precipitate was washed with ethanol twice, once with diluted HCl and dried at 30°C. The prepared nanoparticles were subjected to further treatment with HCl in order to activate the surface, and the resulting nanoparticles were then used in the antibacterial tests.

-Preparation of cynex921 modified silica nanoparticles (CY-SNPs):

The surface modification of silica NPs with cyanex $_{921}$ was performed as following: the surface of the prepared silica NPs was modified by impregnation of 1 g of the synthesized silica NPs in 50 ml ethanol solution containing 0.2 g cyanex $_{921}$. This mixture was stirred for 1 hr. at room temperature followed by removal of ethanol by evaporation at 100 °C down to around 10 ml. The obtained suspension was then dried at 35 °C before use.

Characterization

Various techniques have been used to characterize the prepared native and functionalized silica nanoparticles.

The surface topography and particle size information was given through sample scanning by electron microscopy (SEM). The SEM samples were prepared by placing a drop of the suspended silica particles on a cleaned glass slide and left to dry at room temperature until all the water was evaporated. The glass slide was gold platted using the sputter coater for three minutes. The image obtained used to measure the size of 10 random particles and the average was taken as the particle size. The elemental analysis was given by Energy dispersive X-ray spectroscopy (EDS), The Synthesized spherical silica nanoparticles were subjected to x-ray diffraction (XRD) analysis. ((XRD, XRD 7000, Shimadzu, Japan) studies were performed with, Cu Kα radiation (λ = 1.54 nm) in the 2θ range of 30–80 operate data voltage of 40 kV and a current of 30 mA and finally FTIR spectroscopy was applied to get information about structure and bonds of the silica nanoparticles under study.

Antimicrobial activity studies

- Disc diffusion method

The disc diffusion method was used to screen the antimicrobial activity of the prepared silica nanoparticles against a variety of microorganisms including the candida albicans, and the gram negative (*Escherichia coli, Pseudomonas sp.* and *Salmonella sp*.) bacteria as test microorganisms. The disc diffusion method was also used to screen the antimicrobial activity of known commercially available standard drugs *viz*. ciprofloxacin, amikacin, piperacillin/ tazobactam and cefoperazone antibiotics in order to use as a sort of help to understand the mechanism of action of our test materials and as a comparison issue. For that purpose antibiotic discs were purchased from Oxoide; the nutrient agar was the cultivating media.

-The minimum inhibitory concentration (MIC) method

The antimicrobial activities of the prepared nanoparticles against four types of bacterial strains *viz.* the gram positive microorganism methicillin resistant staphylococcus aureus (MRSA) and the gram negative microorganisms viz. *E.coli*, *klebsiella sp.* and *pseudomonas sp*. were evaluated using the minimum inhibitory concentration (MIC) studies. More than one organism was tested to increase the chance of detecting antibacterial activities. The microorganisms were preserved in nutrient agar slants flooded with 40% glycerol at -20 ^{o}C. Microorganisms were grown at 37^{o}C in nutrient broth prior to use.

For the MIC studies, a group of serial descending (5.0 - 0.10 mg/ml) concentrations of well suspended nanoparticles were carefully prepared in autoclavable screw capped glass tubes having freshly autoclaved nutrient broth media dissolved in doubly distilled water. A quantity of 50µL of standard bacterial suspensions was inoculated in each tube and incubated in a shaking incubator at 37^{o}Cfor only 24 hours. Negative controls have been used to visually differentiate positive and negative results. All steps have been performed under sterile conditions using laminar flow hood. The lowest concentration that gives no growth result on visual observation is considered as the MIC of the SNPs with the organism.

Results and Discussion

Preparation of native and modified silica nanoparticles

The preparation of silica nanoparticles using sodium silicate solution as precursor is among the light attracting methods, hence it is an economic and available source which makes it some kind of favored over the typical tetraethyl orthosilicate [30]. As a cationic surfactant, CTAB was used which is, according to Abou Rida et.al [31], is favored over other shorter chain length surfactants based on the size of the resulting particles.

Modifiers of the prepared nanoparticles were chosen under the seeking well to find a double actioned silica based nanoparticles to work as bactericidal, which is intended to be of great benefit to many industrial facilities. Phosphine derivatives remain underexplored as potential antimicrobials [10, 11]. These compounds provide a large pool of potentially biologically active molecules with vast structural diversity, mainly due to the ease with which they can be modified chemically [12]. Phosphines also provide a simple means of introducing metal complexes into biologically active molecules, via coordination of the lone pair, further expanding the range of inorganic groups that can be explored. Cyanex921 is well known for its great ability of metal removal under diverse conditions [32-34]. The assessment of the antimicrobial activities of the trioctylphosphine oxide modified silica NPs is rarely reported in the literature.

Characterization of the prepared nanoparticles

SEM

The SEM images are presented in Figure (1). The mean diameter of the particles has found to be 35nm.

EDS

The EDS elemental analysis of silica nanoparticles was acquired using Oxford X-Max 20, a component attached to the SEM instrument. The peaks recorded around 1.9 Kv and 0.5 Kv are the binding energies corresponding to Si and O, respectively and are shown in Figure (2, a), which confirms the presence of silicon and oxygen with content around the stoichiometric composition. The ESD elemental analysis for cyanex921 modified silica nanoparticles is shown in Fig.(2, b) with additional peak at around 2.1 Kv corresponding to phosphorous from the cyanex921 moiety , also observed that the percent of carbon is higher regarding the high content of carbon from the organic modifier.

Tables (1) represent the resulting ratios from EDS analysis for silica NPs and cyanex921 modified silica NPs, respectively.

FTIR spectra

The Fourier transform infrared (FTIR) spectra of the $Cyanex_{921}$, the prepared silica nanoparticles and the organically modified nanoparticles were recorded and shown in Figures (3 and4) respectively.

FTIR spectrum of trioctylphosphine oxide shows the characteristic vibrational stretching of the P=O bond at 1146 cm^{-1}, C-H bonds from the alkyl chains at 2850 and 2919 cm^{-1}, and the P-C bond at 1465 cm^{-1}.

FTIR spectrum of silica NPs shows the following bands:

The strong broad band detected at ~ 468 cm^{-1} corresponds to the bending mode of Si-O-Si bond.

The bands at ~970 cm^{-1} and ~802 cm^{-1} can be assigned to the asymmetric vibration of Si-OH bond [35], and assymetric vibration of Si-O bond respectively.

The intense and broad band appearing at ~1033–1220 cm^{-1} is assigned to the antisymmetric stretching vibrations of Si-O-Si siloxane bridges [36].

The absorption band at ~1079 cm^{-1}within the previously mentioned range is corrosponding to asymmetric vibration of Si-O bond.

The band at ~1641 cm^{-1}appears because of scissor bending vibration ofmolecular H2O [37]. An intense characteristic absorption band around 3300–3500 cm^{-1} arises due to the O H stretching vibration mode of $Si(O Si)_n(OH)_{4-n}$ (n= 2–4) linkage of the solid state network structure of silica or due to the unbounded absorbed H_2O[37,38]. After being organically modified with the phosphorus containing compound $cyanex_{921}$, the nanoparticles were subjected to further study by FTIR technique to assure the attachment with the original nanoparticle molecules. The result of such study is shown in fig (5) and it is obvious from the figure that the three broad bands have been sharpened and most of the beaks existing are sharp beaks. All the bands that were assigned for oxygen involved vibrations have been changed ; this is due to the new bond formed between one oxygen atom from the silica molecule and the phosphorus atom from the CYANEX compound. The strong broad band at ~ 468 $cm^{-1}$is shifted and converted into a sharp beak at 450 cm^{-1} which indicates the restriction of the bending vipration of Si-O-Si bond. The center of the intense absorption band around 3300–3500 cm^{-1} have been shifted from 3460 cm^{-1} into 3470cm^{-1}. The band at 1641 cm^{-1} also has been shifted to 1676cm^{-1}. Two new characteristic bands detected at ~1142 cm^{-1} and 960$cm^{-1}$is characteristic for C–P stretching andvibrational stretching of the P=O bond respectively[39]

A new strong characterstic band appeared at~2925cm^{-1} is assigned for the CH2 stretching mode of the cyanex 921 molecule[40].

XRD

Typical silica characteristic is observed at

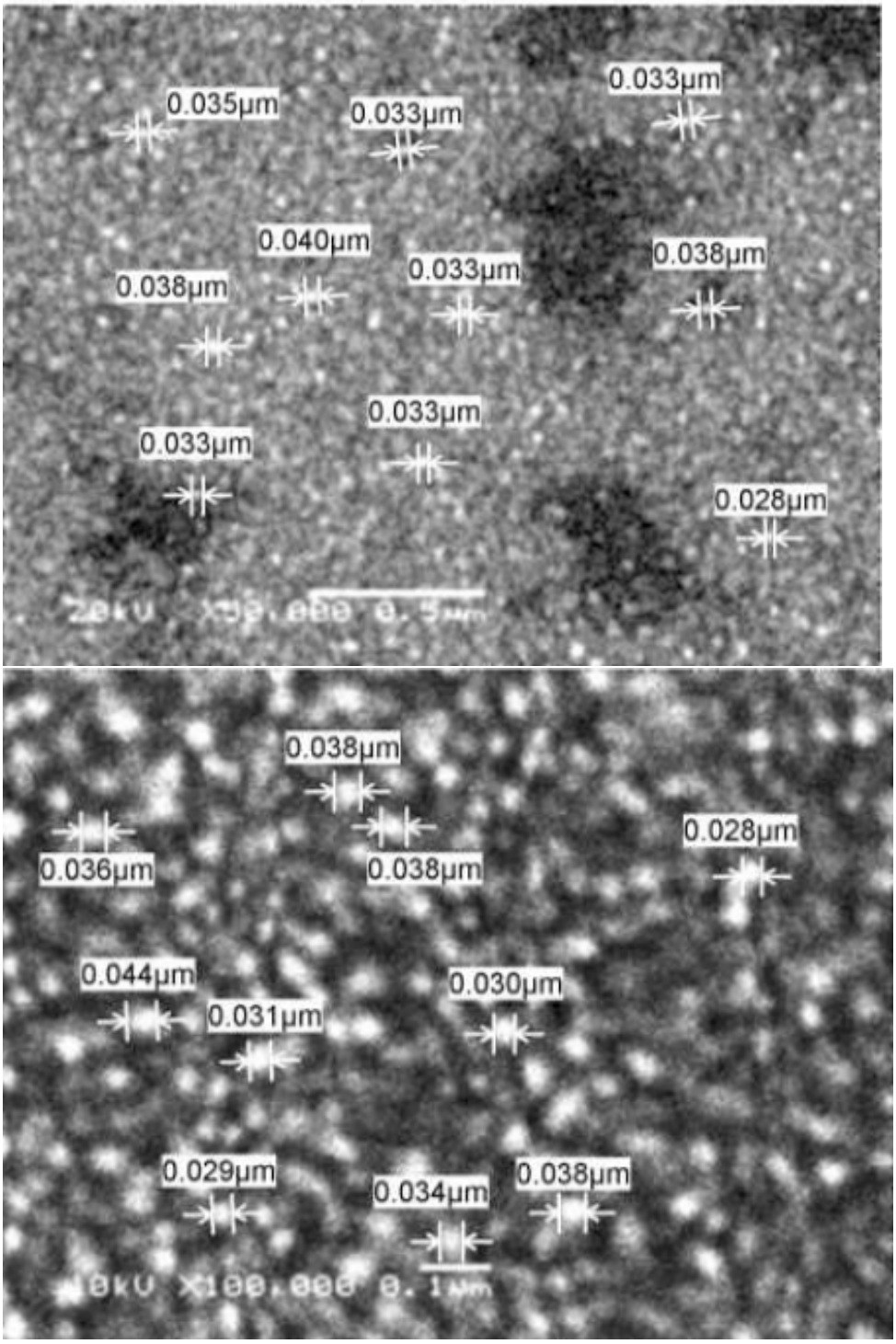
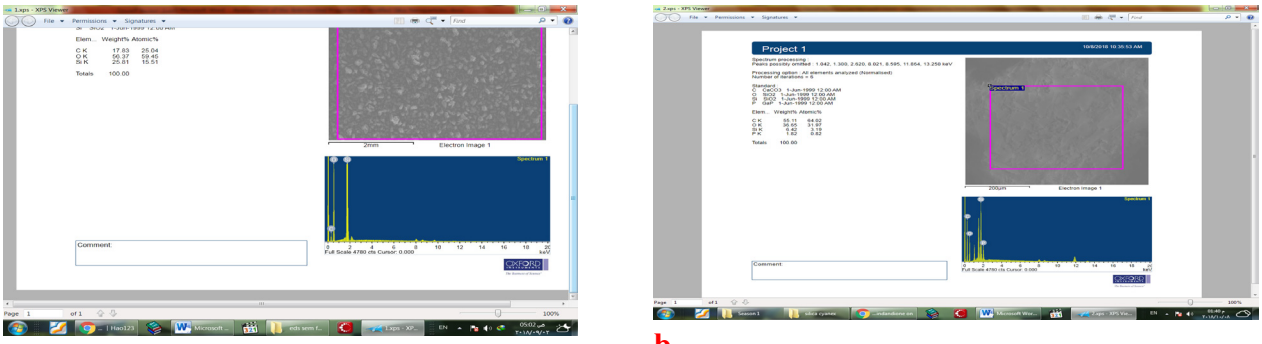
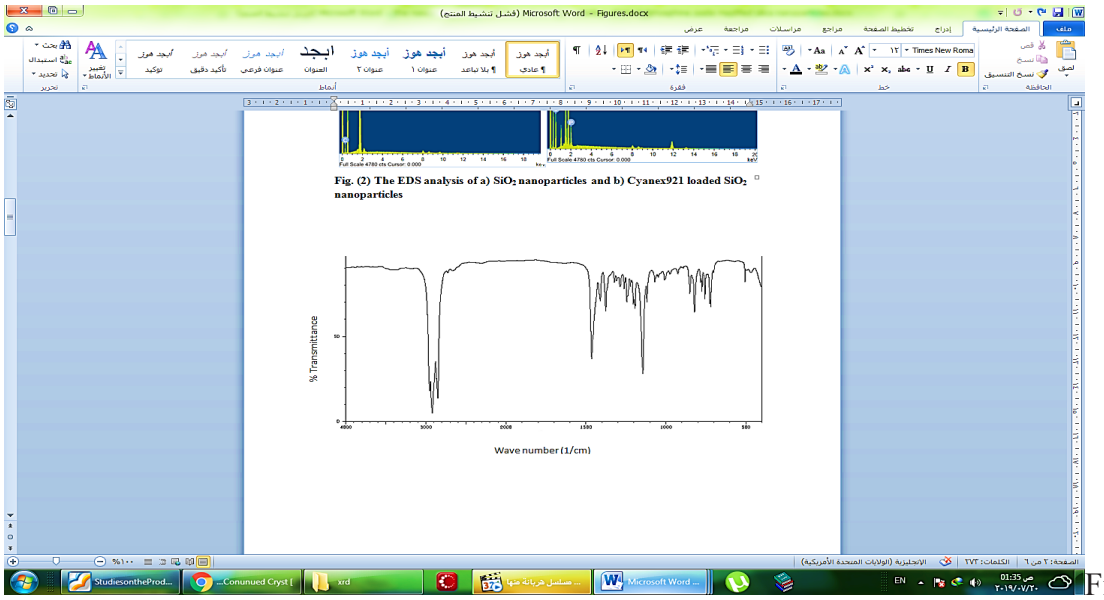


Fig. 1. SEM image of the prepared SiO2 nanoparticles



a b

Fig. 2. The EDS analysis of a) native SNPs and b) CY-SNPs nanoparticles



Fig

Fig. 3. FTIR spectra of cyanex 921 (Trioctyle phosphine oxide)

b

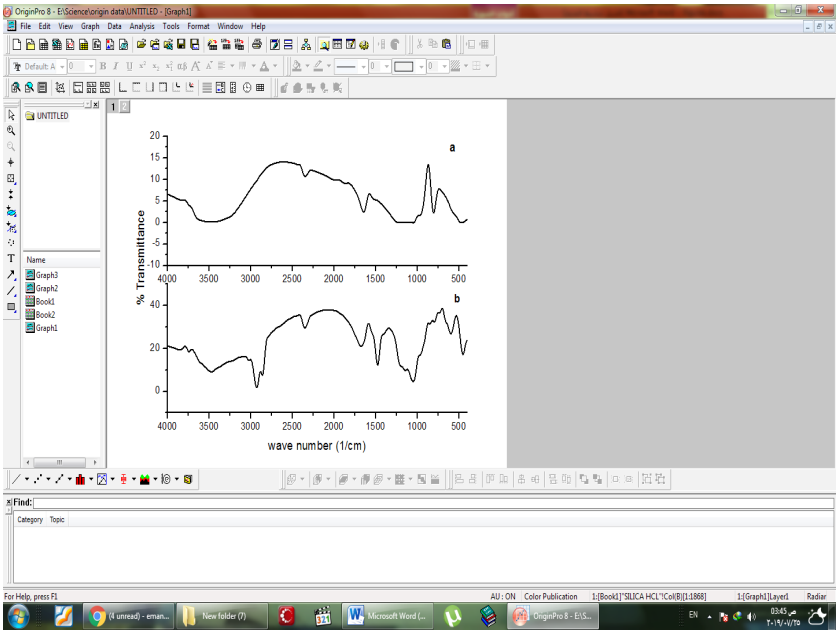


Fig. 4. FTIR spectra comparison; a) native SNPs, b) modified CY-SNPs

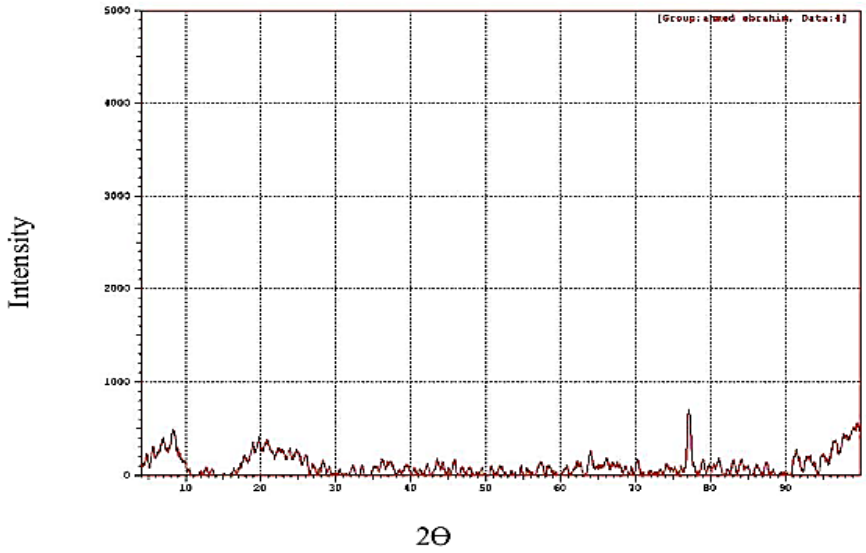


Fig. 5. XRD resulting pattern of silica nanoparticles

broad peak centered at $2\Theta=20^{o}$ which indicate that the sample is amorphous. Figure (5) shows the XRD resulting pattern of silica nanoparticles.

Zeta potential measurements

Zeta potential measurements are recorded for both the native and the modified nanoparticles. Figure (6) show the results.

The value of the potential was found to be -19.6 mV for the silica nanoparticles and 40.7mV for the $CYANEX_{921}$ modified silica nanoparticles. The high potential at the surface indicates the low tendency of the nanoparticles to aggregate.

The antimicrobial activity studies

Preliminary antimicrobial activities using the disc diffusion method reveals that the native SNPS didn't show any activity against the tested microorganisms. For the modified CY-SNPs, the results of the well diffusion experiments revealed that the modified CY-SNPs exhibited inhibitory activity against the tested three bacterial strains as shown in Figure (7). The values of the zone diameter corresponding to each concentration of the modified CY-SNPs are presented in Table (2). On the contrary, the modified CY-SNPs didn't show any inhibitory effect on candida albicans. The results of the disc diffusion method indicate the potentiality of the modified CY-SNPs as antibacterial agents. Quantitative studies applied via the MIC measurements give the specific values of the MICs. Figure (8) shows the tubes of the experiment. The antimicrobial activities of the prepared nanoparticles against the four types of bacterial strains viz. the gram positive microorganism methicillin resistant staphylococcus aureus (MRSA) and the gram negative microorganisms viz. *E.coli*, *klebsiella sp*. and *pseudomonas sp.* were evaluated using the minimum inhibitory concentration (MIC) studies. More than one organism was tested to increase the chance of detecting antibacterial activities. The lowest concentration that gives no growth result on visual observation is considered as the MIC of the SNPs with the organism. The results of the antimicrobial activities of the prepared SNPs are presented in Table (3).

As it can be noticed in Table 3 , the native SNPs didn't show any activity against the tested four bacterial strains over a serial descending concentration of 5.0- 0.1. On the other hand, the modified CY-SNPs have shown high efficacy against the four types of bacterial strains under study. The lowest concentrations of CY-SNPs that give no growth result on visual observation were found to be 0.20, 0.50, 1.0 and 0.50 for *E.coli*, *Pseudomonas sp., Klebsiella sp*. and *MRSA*, respectively. The obtained results of the present study are comparable or better than the results recently published by Ignatova-Ivanova Ts et. al. 2015) [41]. Table (4) summarizes the MIC of the native SNPs and the modified CY-SNPs against the investigated bacterial strains.

The mechanism by which nanomaterials exert their antimicrobial effect stills an area of research. Their mode of action may be different from that of antibiotics but it is may be more effective according to the resistance profile (Table 5). The enhanced antimicrobial activity of nanoparticles can be attributed to their increased surface area available for interactions, which enhances bactericidal effect than the large sized particles; hence, they impart cytotoxicity to the microorganisms [42]. According to Li et.al. [43], they may be acting through one of the following mechanisms: photocatalytic production of reactive oxygen species that damage bacterial cell components, compromising the bacterial cell envelope, interruption of energy transduction, or inhibition of enzyme activity and DNA synthesis. Other factors are controlling susceptibility of bacteria to nanoparticles such as the type of the cell wall [44]. It seems also that the degree of cytotoxicity on the microorganism is size dependent [45]. The cellular membranes of most bacteria are negatively charged and have proven to be the target site of cationic biocides [46]. The antibacterial mechanism of biocidal could be proposed to be penetration into the cell wall and destructive interaction with the cytoplasmic membrane, followed by the leakage of intracellular components and consequent cell death. A recent report has demonstrated the antibacterial activity of mesoporous silica nanoparticles on both Gram positive and Gram negative microbes. The mechanism of the antibacterial activity of mesoporous silica nanoparticles was attributed to the electrostatic interaction of phosphate groups on the microbial cell wall and the cationic head group of the mesoporous silica nanoparticles. Also, the organic tail region embeds itself in the lipid bilayer. This, in turn, leads to the free flow of electrolytes out of the microbe and causes the cell death. This is believed to be the mechanism of cell death [47].

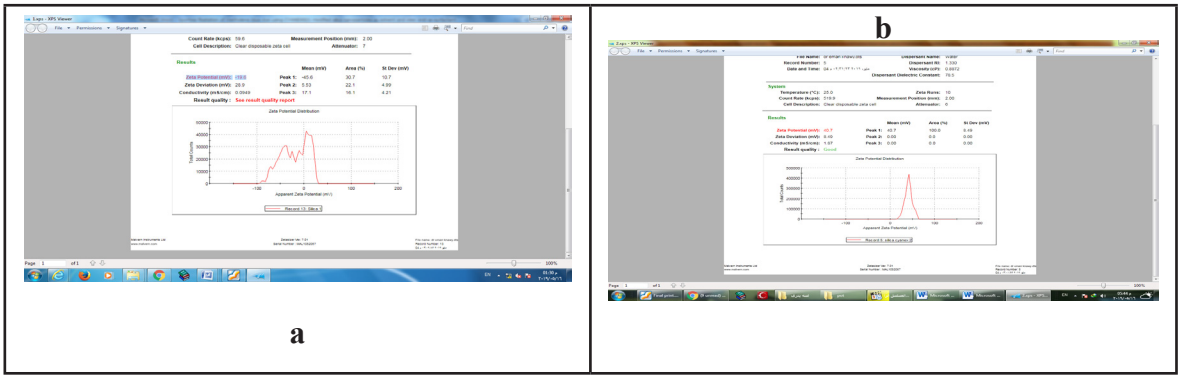


Fig. 6. Zeta potential of (a) native SNPs; (b) modified CY-SNPs

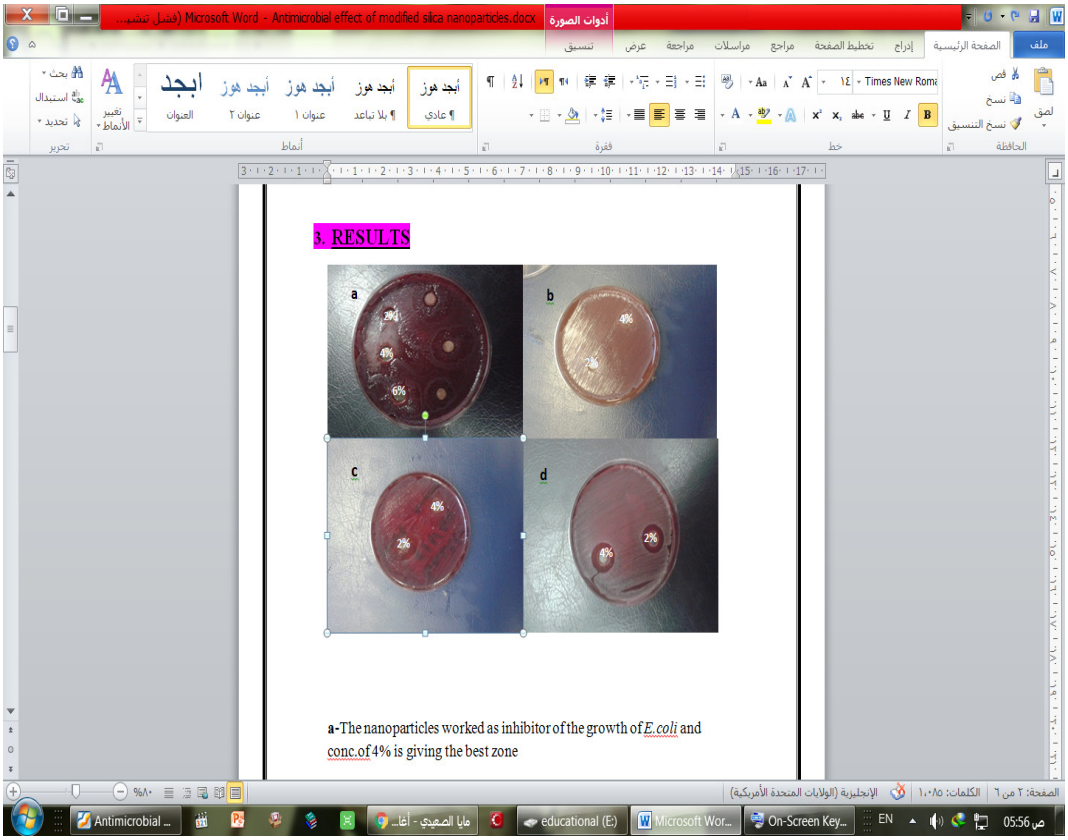


Fig.7. Microorganisms grown on blood nutrient agar plates and different concentrations of modified silica nanoparticles were applied using well diffusion method (a) E.coli, (b) candida albicans, (c) Salmonella spp., and (d) Pseudomonas spp.

Fig. 8. The tubes containing bacteria and nanoparticles suspended in nutrient broth

The four types of bacterial species under study have shown similar response to silica nanoparticles, whether or not the mechanism of interaction between each type of bacterial cells and the nanoparticles is the same, Cysnex 921 modified silica nanoparticles appear to have good antibacterial activity.

Conclusion

In conclusion, in this study, we have successfully synthesized the spherical silica nanoparticles using the sol-gel method. The use of cationic surfactant, Cetyl Trimethyl ammonium Bromide (CTAB) is critical to the formation of the spherical silica nanoparticles. The native SNPs were organically modified using the trioctylphosphine oxine (cyanex921). The native and modified SNPs were characterized using SEM, ESD, FTIR and XDR. The antimicrobial activities of the prepared nanoparticles against four types of bacterial strains viz. the gram positive microorganism methicillin resistant staphylococcus aureus (MRSA) and the gram negative microorganisms viz. *E.coli*, *klebsiella sp.* and *pseudomonas sp.* were evaluated using the minimum inhibitory concentration (MIC) studies. The antibacterial studies suggest that the trioctylphosphoine oxide modified silica nanoparticles can be used as potential drug candidature to treat various diseases.

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تقييم الأنشطة المضادة للميكروبات لجزيئات السيليكا النانونية المعدلة بأكسيد ثلاثي الفوسفيلين

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الجسيمات النانونية للسيليكا هى جسيمات من السيليكا يتراوح حجمها من ١ الى ١٠٠ نانومتر. تم، فى هذه الدراسة ، تحضير الجسيمات النانونية للسيليكا باستخدام سيتيل ترای ايثيل أمونيوم بروميد مع سيليكات الصوديوم . جسيمات السيليكا النانونية التى تم تحصيرها خضعت للتعديل بمادة عضوية وهى أكسيد الترای أكتيل فوسفين (سيانكس٩٢١) لانتاج جسيمات نانونية معدلة للسيليكا. كلا من الجسيمات النانونية للسيليكا الأصلية والمعدلة تم توصيفها باستخدام مجهر المسح الالكترونى والذى أظهر جسيمات كروية بمتوسط حجم ٣٥ نانومتر. التحليل العنصرى تم اجراؤه باستخدام جهاز طيف تشتت الطاقة. بالنسبة للجسيمات النانونية للسيليكا ، البروز المسجل حول ١,٩ و ٠,٥ كيلوفولت يمثل طاقات الارتباط التابعة للسيليكون والاكسجين بالترتيب.بالنسبة للجسيمات النانونية المعدلة بالسيانكس ٩٢١ يظهر بروز اضافى عند ٢,١ كيلوفولت وهو يتبع ذرة الفوسفور من جزىء السيانكس٩٢١. تحليل حيود الأشعة السينية للمسحوق المحضر لدراسة حالة التبلور للجسيمات النانونية المحضرة للسيليكا أثبت انها غير متبلورة بدليل ظهور بروز واسع فى تمثيل الحيود متمركز عند $20^{o}=2\Theta$. القياسات الخاصة بالأشعة تحت الحمراء أثبتت تحميل السيانكس ٩٢١ على سطح الجسيمات النانونية للسيليكا الأصلية . النشاط المضاد للبكتيريا للجسيمات النانونية للسيليكا الأصلية والمدلة بالفوسفين تم تقييمه ضد الميكروبات الموجبة الجرام والسالبة الجرام باستخدام دراسات الحد الأدنى للتركيز المثبط. النتائج التى حصلنا عليها أثبتت أن الجسيمات المعدلة بالسيانكس ٩٢١ لها تأثير محتمل مضاد للبكتيريا ضد البكتيريا الموجبة الجرام (المكورات العنقودية المقاومة للميثيسيلين) والبكتيريا السالبة الجرام (إى-كولاى ، جنس الكليبسيللا , جنس الزيدوموناس) والحد الأدنى للتركيز المثبط التابع لكل منها تم تعيينه. الجسيمات النانونية للسيليكا الأصلية لم تظهر اى نشاط مصاد للبكتيريا ضد الأنواع المذكورة سابقا فى تركيزات تتراوح من ٠,١و ٥,٠ مللى جرام / مللى لتر. الية النشاط المضاد للبكتيريا للجسيمات النانونية للسيليكا المعدلة بالفوسفين تمت مناقشتها. الدراسة الحالية أثبتت أهلية الجسيمات النانونية للسيليكا المعدلة بالسيانكس ٩٢١ للاستخدام كعوامل مضادة للبكتيريا.