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Cyclic voltammetry, photocatalytic and antimicrobial comparative studies of fabrication Fe₃O₄ and Fe₃O₄/PAN nanofibers

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Abstract

This study reports the properties of green mediated synthesized iron oxides nanoparticles (Fe₃O₄ NPs) from peel extracts of pomegranate plant and its polyacrylonitrile/iron oxide composite nanofibers (Fe₃O₄/PAN). The following were used to characterize the synthesized nanoparticles and its polymer nanofibers; FT-IR, UV-Visible spectroscopy, scanning electron microscope SEM, TEM and cyclic voltammetry. The antimicrobial activities of synthesized nanoparticles were investigated against selected bacterial pathogens. For the plant extract, FTIR revealed OH characteristics peaks at 3271 cm⁻¹ and 1600 cm⁻¹ while the absorption peaks at 577 and 430 cm⁻¹ showed successful reduction of the precursor to Fe₃O₄ nanoparticles. The SEM images showed a spherical morphology of Fe₃O₄ and that of the composite with entrapped Fe₃O₄ into the PAN nanofibers. Photocatalytic process showed that the synthesized Fe₃O₄ nanoparticles has degradation efficiency of 71.36% and the nanofibers exhibited efficiency of 22.68% towards methylene blue (MB) dye. However, further kinetic analysis of the degradation process put Fe₃O₄/PAN nanoparticles (NP) at a better correlation coefficient of 0.9239 than the Fe₃O₄ nanoparticles. Electrochemical studies using cyclic voltammetry showed that PAN functionalized with Fe₃O₄ is more electroactive as compared to the other electrodes studied. The anodic peak potential at 599 mV also confirmed the presence of Fe₃O₄ in the nanocomposite Fe₃O₄/PAN. The antimicrobial studies revealed that as the concentration of the green mediated Fe₃O₄ nanoparticle increases in the composite Fe₃O₄/PAN an excellent antimicrobial activity against selected pathogens were observed, showing Fe₃O₄ nanoparticles potentials to control pathogens of public health significance.

1. Introduction

The development of inexpensive, environmentally and eco-friendly methods for the synthesis of nanoparticles and its composite has been made possible through nanotechnology [1–3]. Nanocomposites from metal oxides nanoparticles and polymer nanofiber are of great importance to researcher. Nanofibers from polymers have found various applications in the medical field such as in the detection of biological analytes [4], drug delivery [5], magnetic resonance imaging (MRI) [6], cancer therapy and diagnosis [7, 8]. Other applications include; industrial, agricultural, environmental, and waste management.

The green method for the synthesis of metal oxides nanoparticles have been widely reported and also established [9]. Many metal oxides nanoparticles have been successfully synthesized using extracts from plants [10, 11]. Metal oxide nanoparticles have chemical and physical properties such as particle size, density and surface area [12]. Metal oxide nanoparticles have found applications in areas like sensors, photochemical, and microelectronic circuit’s fabrication. Nanoparticles of various metal oxide have been synthesized, these include...
nickel oxide (NiO) [13], zinc oxide (ZnO) [14], copper oxide (CuO) [15], and iron oxides (Fe₃O₄) [16], to mention but few. Iron oxide nanoparticles (NPs) are of special interest among other nanomaterials because of its high surface area to volume ratio, fast kinetics, strong adsorption capacities, [17] and great magnetic properties [18].

Functionalization of different polymers with different nanoparticles to form their corresponding nanocomposites has been reported. Iron oxide (Fe₃O₄) nanoparticles and its nanocomposites have shown great applications in magnetic recording [19], toners [20], wastewater treatment [21–24], medicine [25], bioprocesses [26, 27], magnetic resonance imaging [28–30], magnetic data storage devices [19], and xerography ink [20]. Furthermore, polymeric nanofibers and their nanocomposites are formed by electrospinning process [31].

Electrospinning method is simple and cost-effective in the production of nanofibers [31]. It gives a more convenient way to fabricate infinite, continuous fibers and has found applications in various field such as infiltration [32, 33], biomedical films [34, 35], and scaffolds for tissue engineering [36].

This innovative method encourages the blending of a variety of polymers and nanoparticles to yield superfine fibers. Magnetic nanoparticles based composites nanofibers have been reported in literatures, example of such electrospun polymer-based composite nanofibers are polyaniline/Fe₃O₄ [37], poly(F-caprolactone)/FePt [38], poly-L-lactide/Fe₃O₄ [39], polymethylmethacrylate/Fe₃O₄ [40], and poly(ethylene oxide)/Fe₃O₄ [41]. The antimicrobial activities of nanoparticles and their polymer nanocomposites depend on the crystallinity, concentrations and the substrate from which the nanomaterial was synthesized [42].

Pathogens are microorganisms which are capable of causing ill-health to humans and animals [43]. Pathogenic bacteria such as Salmonella Typhimurium, Salmonella Enteritidis, Escherichia coli, Vibrio cholera, Listeria monocytogenes has been blacklisted and reported to be of public health significance [43, 44]. There have been several efforts to control bacteria pathogens through the use of antimicrobials such as antibiotics. However, in recent years, there have been cases of antibiotic resistance to this pathogens, thereby causing a search for method have shown excellent antimicrobial properties against pathogens [45]. The increasing threat posed to food safety and public health by evolving bacteria pathogens calls for concern, hence, it is necessary to investigate the potentials of Fe₃O₄ and Fe₃O₄/PAN nanofibers as antimicrobial agents against pathogens of public health concerns.

This work, therefore, reports the investigation of the spectroscopic, morphological, and antimicrobial properties of green mediated based iron oxide nanoparticles and its functionalized PAN composite nanofibers.

2. Materials and methods

2.1. Reagents and apparatus
Pomegranate plant from the community, FeSO₄·6H₂O, N, N-Dimethylformamide, anhydrous, 99.8% (DMF), and Polyacrylonitrile (PAN) powder obtained from Sigma-Aldrich chemicals. Equipment such as oven, UV-visible spectrophotometer (Agilent Technology, Cary series UV-vis spectrometer, USA), Fourier transformed infrared spectrometer (Agilent Technology, Cary 600 series FTIR spectrometer, USA, Germany), Transmission electron microscopy (Tecnai G2 spirit FEI, USA), high resolution scanning electron microscope (Zeiss Ultra Plus 55 HRSEM were used to characterize the synthesized nanoparticles, polymer nanofibers and their nanocomposite.

2.2. Green synthesis of the Fe₃O₄ nanoparticle
Pomegranate plant was washed thoroughly and the peel was cut into pieces and dried up in an oven for 48 h at 40 °C. The dried peel was then blended to a very fine powder, and 20 g powder was boiled in 250 ml distilled water. The extract was filtered using vacuum pump filter. About 50 ml of 0.05M FeSO₄·6H₂O were add to 50 ml pomegranate extract drop wisely under continuous stirring. The solution was then heated at 80 °C for some minutes until about 2 h at 40 °C. The extract was then centrifuged for few minutes at 4 °C at 6000 rpm. The suspension obtained were dried for 30 min at 70 °C temperature obtain nanoparticles in powder [46].

2.3. Fabrication of PAN and its composites Fe₃O₄/PAN nanofibers
Polyacrylonitrile PAN was pre-dried at 60 °C for 24 h and then dissolved DMF to make 16 wt%. Electrospinnable polymer solution was suctioned into 20 ml syringe and 22 kV voltage was applied, the flow rate and the tip-collector distance were fixed at 0.15 ml h⁻¹ and 15 cm respectively. Nanofibers were placed on an aluminium foil plate and the electrospinning was performed at an ambient temperature. The nanofibers were dried overnight at room temperature to eliminate water and solvent from the produced nanofibers. The same procedure was followed for the composite by measuring 1:1 of PAN and Fe₃O₄ nanoparticles to make 16 wt% required spinnable solution.
2.4. Characterization of Fe$_3$O$_4$, PAN, and its composites Fe$_3$O$_4$/PAN nanofibers

Spectroscopy characterization such as UV-vis was performed on Perkin Elmer Lambda 650 UV-visible spectrometer, and Fourier-transform infrared spectroscopy (FTIR). The absorbance scans were run over the wavelength range of 200 to 800 nm. The morphological and size measurement were also performed on scanning electron microscope (SEM), transmission electron microscopy (TEM) characterization were performed. Image J software was used to measure the diameter of the nanofibers and the TEM image of the nanoparticle.

2.5. Cyclic voltammetry studies

Electrochemical characterization of the synthesized nanoparticles and its polymer nanofibers was carried out by using cyclic voltammetry (CV). Cyclic voltammetry measurements were carried out by using a dropense software driven mini PGSTAT 302. The screen print electrode consists of three electrodes which are Ag/AgCl as reference electrode, counter electrode and a carbon working electrode. The carbon electrode (working electrode) was modified using the drop-dry method. Separate drop of Fe$_3$O$_4$ NPs, PAN and Fe$_3$O$_4$/PAN were cast on the electrode respectively and dried in the oven for 2 min at temperature of 50 °C. The voltammogram for the bare and modified SPC electrode were measured in 5 mM potassium hexacyano-ferrate (III) (K3Fe(CN)6) solution prepared in 0.1 M phosphate buffer solution (PBS) as a supporting electrolyte.

2.6. Photocatalytic studies

The photodegradation of methylene blue (MB) dye was studied using the synthesized Fe$_3$O$_4$ nanoparticles and the PAN/Fe$_3$O$_4$ nanofibers. The methylene blue solution (20 mg L$^{-1}$) was prepared and 100 ml used for the photocatalytic study. The solution was first agitated for 30 min in a dark environment for proper equilibration after which 10 mg of the nanoparticles and 62.5 mg of the nanofibers (5 × 5 cm) were used separately. The dye and nanomaterial solution was stirred for 20 min and the UV light was switched on. The reaction was carried out in a photocatalytic reactor for 2h while aliquot samples were taken to study the rate of dye degradation using UV-vis spectrophotometer. The degradation study was carried out within the wavelength of 350–740 nm and the MB absorption maximum recorded at 664 nm.

2.7. Antimicrobial activity of PAN, Fe$_3$O$_4$ and Fe$_3$O$_4$/PAN nanofibers

The antimicrobial activity of synthesized nanoparticles was evaluated using the agar disc diffusion method [47]. Selected pathogens of public health importance such as; *Bacillus cereus*, *E. coli*, *Enterococcus faecalis*, *Enterococcus faecium*, *Enterococcus galinarum*, *Salmonella Typhimurium*, *Salmonella Enteritidis*, *Vibrio cholera* were obtained from the Molecular Microbiology Laboratory, North West University, South Africa. Fresh overnight cultures of test pathogens were adjusted to 0.5 McFarland concentrations and was then diluted twenty-fold (1:20) to obtain 5 × 10$^6$ CFU ml$^{-1}$. Diluted cultures (10$^5$ CFU ml$^{-1}$) of selected pathogens were seeded on Muller Hinton agar prepared according to manufacturer’s specifications and was poured on petri dishes. Fe$_3$O$_4$ nanoparticles and PAN/Fe$_3$O$_4$ nanofibers sols were prepared by dispersing equal mass of nanoparticles/nanofibres in five times volume of dimethylformamide (DMF). The antibiotic (ciprofloxacin 30 μg) was used as positive control while dimethylformamide was used as negative control. Empty antimicrobial disc was singly impregnated with ciprofloxacin (30 μg), DMF, synthesized Fe$_3$O$_4$ nanoparticles and PAN/Fe$_3$O$_4$ nanofibers and were allow to stand for an hour. The impregnated discs were placed at equidistance to each other to prevent overlap on the seeded petri dishes. The experiment was determined in triplicates. Inhibitions zones were observed on plates incubated aerobically at 37 °C for 24 h. Inhibition zones of nanoparticles against selected pathogens were measured using a graduated meter rule in millimetres (mm) and values were recorded.

3. Results and discussion

3.1. Spectroscopic studies using UV-vis and FT-IR

3.1.1. UV-vis spectroscopy

The UV-Visible spectrum of Fe$_3$O$_4$ nanoparticles synthesised from the aqueous pomegranate extract is shown in figure 1. The absorption peak at 290–450 nm indicates the formation of Fe$_3$O$_4$ nanoparticles.

3.1.2. FT-IR spectroscopy

The functional groups of pomegranate peel extract and the synthesized were determined and predicted by using the FT-IR spectroscopy. The spectra of the pomegranate extracts revealed a strong absorption bands at 3573, 2950, 1740, 1239, and 1068 cm$^{-1}$ as shown in figure 2(a). The peak at 3573 cm$^{-1}$ in the extract represent O-H been the major acting as reducing agent. The peak at 2950 cm$^{-1}$ indicates the C-H stretching vibrations of the –CH2 functional group [48], while 1740 cm$^{-1}$ and 1239 cm$^{-1}$ corresponds to the C-H bending of aromatic
compound and asymmetric vibration of sulphate group \[34\] and lastly the 1068 cm\(^{-1}\) represent the C-O stretching band. All bands remain shielded while on the spectra for Fe\(_3\)O\(_4\) nanoparticles shown in figure 2(b), there were appearance of peaks at 775 cm\(^{-1}\) representing the existence of aromatic C-H bending band and peaks at 577 and 430 cm\(^{-1}\) signifies the successful synthesis of Fe\(_3\)O\(_4\) nanoparticles from Fe-O stretching vibration mode. The metal oxygen band at 577 cm\(^{-1}\) corresponds to stretching vibration of metal at the tetrahedral site while at 430 cm\(^{-1}\) indicates metal at octahedral site \[49\].

Figure 1. UV-Visible spectra of Fe\(_3\)O\(_4\) nanoparticles.

Figure 2. FT-IR spectra of (a) pomegranate extract and (b) Fe\(_3\)O\(_4\) (c) Fe\(_3\)O\(_4\)/PAN nanofibers.
3.2. Morphological studies: SEM and TEM

3.2.1. Scanning electron microscopy (SEM)

The surface morphologies of the prepared samples were studied using SEM. Figure 3(a) shows the SEM image for the PAN nanofibers only with evenly distributed nanofibers of equal diameters ranging from 6 to 12 nm, while figure 3(b) shows PAN doped with Fe₃O₄ nanoparticles. The changes observed in the morphology of the nanofibers is an evidence of the Fe₃O₄ interacting with the polymer forming a web like structure round the nanofibers strands resulting in an increase in the diameter ranging from 8 to 14 nm. On the other hand, the figure 3(c) the SEM image for the Fe₃O₄ nanoparticles, the SEM image confirms that the particles are cubic in shape [30].

Figure 3. SEM images of (a) 16 wt% PAN only, (b) Fe₃O₄/PAN nanofibers and (c) Fe₃O₄ and the diameter distribution (i), and (ii) for PAN, and Fe₃O₄/PAN respectively.
3.2.2. Transmission Electron Microscopy (TEM)
In figure 4, the TEM image of the synthesized Fe₃O₄ nanoparticles showed that the nanoparticles were well dispersed in colloidal solution with cubic shape ranging from 10 to 50 nm. The average well distributed particle size of 30 nm.

3.3. Electrochemical studies of Fe₃O₄ and Fe₃O₄/PAN at SPC electrode
Comparative electrochemical voltammogram of bare SPC, SPC-Fe₃O₄ and SPC-PAN and SPC-Fe₃O₄/PAN modified electrodes at 25 mVs⁻¹ scan rate in 5 mM potassium hexacyano-ferrate (III) (K₃Fe(CN)₆) solution prepared in 0.1 m PBS as a supporting electrolyte were studied. The cyclic voltammogram obtained are presented in figure 5. A pair of anodic peak current was observed at 247 and 599 mV on SPCE-Fe₃O₄ electrode which are assigned to Fe(CN)₆⁴⁻/[Fe(CN)₆]₃⁻ and Fe₃O₄ respectively. The SPCE-Fe₃O₄/PAN electrode voltammogram showed more electroactive properties. The oxidation peaks current observed at SPCE-Fe₃O₄/PAN is three times greater than the other electrodes. The anodic peak potential observed at 599 mV on the SPCE-Fe₃O₄ and SPCE-Fe₃O₄/PAN confirms the presence of green mediated synthesized Fe₃O₄. The successful functionalization of PAN nanofibers with Fe₃O₄ was also confirmed.
The reaction at the surface of the modified SPCE-Fe₃O₄/PAN and SPCE-Fe₃O₄ electrode was confirmed by the scan rate study at scans ranging from 25 mVs⁻¹ to 300 mVs⁻¹ in 5 mM potassium hexacyano-ferrate (III) solution prepared in 0.1 M PBS. From the voltammogram shown in figures 6(i), 7(i) respectively, increase in scan rate leads to an increase in current response and a shift of potential towards the right at the anode and to the left at the cathode was observed. A linear plot of current versus square root of the scan rate shown in figures 6(ii), 7(ii) respectively, revealed a linear relationship between the current and the scan rate. The regression values at the SPCE-Fe₃O₄/PAN, and SPCE-Fe₃O₄ electrodes were approximately 0.99 which confirms the reaction at the electrode surface to be diffusion controlled reactions.

Stability of the modified electrodes was investigated using cyclic voltammetry for several scans at 25 mVs⁻¹ scan rate in 5 mM potassium hexacyano-ferrate (III) solution prepared in 0.1 M PBS. From the voltammogram shown in figure 8, anodic and cathodic current drop for the first and last scan was higher at the SPCE-Fe₃O₄/PAN as compared with the drop at SPCE-Fe₃O₄NPs. From the stability study, SPCE-Fe₃O₄NPs was more stable than SPCE-Fe₃O₄/PAN.

3.4. Photocatalytic activity
In recent times, nanomaterials are greatly serving as photocatalysts in the degradation of dyes. Figure 9 shows the degradation of the dyes in absorbance terms with respect to irradiation time. From figure 9, there was a remarkable decrease in the first 30 min of the reaction but subsequently, the rate got slower. In figure 10, the degradation rate was gradual and the concentration of the dyes continued to decrease. During the degradation process, the blue colour of the dye tends to be lighter which was due to the destruction of the chromophores in...
Figure 8. Cyclic voltammogram of stability study (i) SPCE- Fe₃O₄/PAN, and (ii) SPCE- Fe₃O₄ in 5 mM potassium hexacyano-ferrate (III) solution prepared in 0.1 m PBS at scan rate 25 mV s⁻¹ for 13 scans.

Figure 9. Showing time dependent UV-vis absorption spectra for Methylene blue dye in the presence of Fe₃O₄ nanoparticles.

Figure 10. Showing time dependent UV-vis absorption spectra for Methylene blue dye in the presence of composite 0.6g PAN and 0.4g Fe₃O₄ nanofibers.
the structure of the compound dye. Further, the degradation efficiencies were calculated using the absorbance results obtained from the Uv-vis at the wavelength of absorption of the dye, 664 nm. The following equation was used:

\[
\% \text{ degradation} = \left(1 - \frac{C_t}{C_0}\right) \times 100.
\]

Where \(C_0\) and \(C_t\) are concentration value at the initial time and at a particular irradiation time \(t\).

The percentage degradation of the nanoparticles and the nanofibers were compared and it was expected that the nanofibers could have greater efficiency due to the impregnation of the Fe\(_3\)O\(_4\) into the PAN. On the contrary, the results showed 71.36% for the Fe\(_3\)O\(_4\) and 22.68% for the composite nanofibers at the 2 h of the reaction which reflects higher degradation efficiencies with the nanoparticles than the nanofibers. The reason may be due to the different shapes of the nanomaterials as their morphologies determines their activities and applications. In addition, photocatalytic process also depends on the available active species which determine the reduction reactions \([51–53]\).

When UV light falls on the photocatalysts, energized electrons are excited leaving holes behind. The holes interact with water molecules to form active radicals \(^{\bullet}\)OH which act as the redox agents while the excited electrons react with oxygen to form superoxide radicals \(^{\bullet}\)O\(_2\) \([51]\). The presence of more holes therefore enhances degradation process. It is therefore presumed that there were enough active sites or holes in the nanoparticles than in the nanofibers. Previous studies using PAN/TiO\(_2\) and PAN/ZnO nanofibers have shown 93% and 91% degradation efficiencies of malachite green dye respectively \([54]\). In another report of adsorption of tetracycline using Fe\(_3\)O\(_4\) and Fe\(_3\)O\(_4\)/PAN enhanced activity was observed with the composite nanofibers than the nanoparticles as against the result recorded in this study as shown in figure 11(b). It is therefore, proposed that the green mediated nanoparticle does has improved photocatalytic activities due to the presence of phytochemicals in the extract used for the synthesis.
The nanocomposite may prevent the aggregation of the incorporated nanoparticles thereby still enhancing the surface area, however, such may not have occurred in this study and this surface area is reduced leading to poor dye adsorption [55].

The degradation reaction rate constant for the nanomaterials were obtained from the pseudo first order equation or Langmuir–Hinshelwood model [54],

\[ -\ln \frac{C}{C_0} = k t. \]  

Figure 11(a) shows the plot of \( \ln C/C_0 \) against \( t \), and the slope of the graph obtained represents the rate constant \( k \). The rate constants are 0.0017 \( \text{min}^{-1} \) and 0.0019 \( \text{min}^{-1} \) for \( \text{Fe}_3\text{O}_4 \) and \( \text{Fe}_3\text{O}_4/\text{PAN} \) respectively. The correlation coefficient of the \( \text{Fe}_3\text{O}_4/\text{PAN} \) is 0.9239 which explains a better fitting to the kinetic model than the correlation value of the \( \text{Fe}_3\text{O}_4 \) at 0.4568.

3.5. Antimicrobial activity

The antimicrobial effect of synthesized polycrylicnitrite/\( \text{Fe}_3\text{O}_4 \) nanoparticles against selected pathogens of public health significance as influenced by level of \( \text{Fe}_3\text{O}_4 \) nanoparticles substitution is presented in figure 12. The antimicrobial activities of polycrylicnitrite (PAN) substituted with \( \text{Fe}_3\text{O}_4 \) increased with increasing substitution with \( \text{Fe}_3\text{O}_4 \). The \( \text{Fe}_3\text{O}_4 \) significantly influenced the antibacterial activity of synthesized composite nanoparticles compared to ordinary PAN. A similar observation was observed against \( \text{Enterococcus faecalis} \), \( \text{Enterococcus faecium} \), \( \text{Enterococcus galinarium} \) and \( \text{Vibrio cholerae} \). PANF 3 gave the highest antibacterial activity compared to ordinary PAN. A similar observation was observed against \( \text{Enterococcus faecalis} \), \( \text{Enterococcus faecium} \), \( \text{Enterococcus galinarium} \) and \( \text{Vibrio cholerae} \). PANF 3 gave the highest antibacterial activity against \( \text{Bacillus cereus} \) (22 mm) while PAN had the lowest (11 mm). \( \text{Bacillus cereus} \) is a gram positive bacteria that colonizes food substrate and on ingestion can cause food borne infections. The zones of inhibition of composite nanoparticles against \( \text{Escherichia coli} \) ranged from 9–17 mm and were highest in PANF 3. As expected, ciprofloxacine (positive control) inhibited the growth of the test pathogens as a standard antibiotic. Ciprofloxacine is one of the main streams of antibiotics often prescribed in the treatment of infections caused by enteric pathogens.

Dimethylformamide (DMF) did not inhibit the growth of all tested pathogens justifying that the observed effect was a product of the activity of the synthesized nanoparticles. The zones of inhibition in \( \text{Fe}_3\text{O}_4 \) ranged from 6–14 mm, PAN (7–18 mm), PANF1 (9–16 mm), PANF2 (11–19 mm), PANF3 (11–22 mm). The zones of inhibition observed against the test pathogens were lower than those obtained in PANF. The antimicrobial activity of the nanoparticles supports the previous observation reported in literature in AgNPs synthesized with \( R. \text{chinensis} \) galls extract and marine algae (\( \text{Ecklonia cava} \)) respectively [55, 56]. Contrary to the above observations, antibacterial activities of the synthesized nanoparticles against \( \text{Salmonella} \text{Typhimurium} \) and \( \text{Salmonella} \text{Enteritidis} \) were not dependent on concentration of \( \text{Fe}_3\text{O}_4 \) NPs. Antibacterial activity was optimum against \( \text{Salmonella} \) pathogens at 1.4 g of \( \text{Fe}_3\text{O}_4 \)NP’s substitution with PAN. The observed antibacterial activity of

\[ A = \text{Fe}_3\text{O}_4 (0.71 \text{ g}); \text{PANF1} = \text{PAN} (0.71) + F (1.4) \text{ g}; \text{C} = \text{PANF2} = \text{PAN} (0.71) + F (2.5) \text{ g}; \text{D} = \text{PANF3}= \text{PAN} (0.71) + F (3.0) \text{ g}; \text{E} = \text{PAN} = (0.71 \text{ g}); \text{Control} = \text{Ciprofloxacine} (30 \text{ µg}), \text{DMF} = \text{Dimethylformamide}. \]  

Figure 12. Antimicrobial activity of nanoparticles against selected pathogens.
the synthesized nanoparticles from pomegranates peel could imply its ability to alter the formation of ROS, DNA replication, aggregation of proteins and interfere with leakages in the cell wall of bacterial pathogens [57–59].

4. Conclusion

The successful synthesis of Fe₃O₄ nanoparticles from pomegranate peel extract and fabrication of Fe₃O₄/PAN nanofibers composite were confirmed by using spectroscopy and morphological techniques. The fabrication of Fe₃O₄/PAN nanofibers composite were performed by electrospinning technique. For characterization of nanofibers and nanofibers SEM and TEM images were used and it was shown that Fe₃O₄ nanoparticles were uniformly combined with the PAN nanofibers and FT-IR spectroscopy and UV-Visible spectra were used to confirm the functional groups and characteristics wavenumber of the nanoparticle. The electrochemical characterization of the electrodes from bare to the modified shows that the modified electrodes of Fe₃O₄/PAN gave a better enhancement and catalytic activities than the bare and other electrode studied. The application of the synthesized nanoparticles and nanofibers in the photodegradation of MB dye has shown some promising effects which can be further developed towards waste water treatment. However, Fe₃O₄/PAN nanofibers composite also exhibited higher antibacterial activity, showing their potential application in water purification, and capable of destroying pathogens or bacteria from waste water. Fe₃O₄/PAN nanofibers composite with contact between nanomaterial and pathogens results in a high antimicrobial efficiency, because the DNA binds when Fe₃O₄ nanoparticles come in contact with pathogens and destroy their metabolism process by damaging the cells and eventually cause death.

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Author contributions

OEF conceptualised and designed the work and was part of the manuscript write-up. OEF, RNM, and SAA carried out the experiments, interpreted the results. SAA carried out the antimicrobial studies, while EEE assisted with the Photocatalytic studies and all authors were involved in the manuscript preparation. All the authors reviewed the manuscript and have agreed to its publication.

Competing financial interests

The authors declare no competing financial interests or any other conflict of interest.

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