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'Synergistic-Cidal' Effect of Amoxicillin Conjugated Silver Nanoparticles Against *Escherichia coli*

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Abstract
The research article presents the synthesis, characterization, and biological evaluation of amoxicillin functionalized with AgNPs with low toxicity and good antimicrobial property which can be produced with silver nitrate and amoxicillin drug in an environmentally friendly method. The synthesized nanoparticles were subjected to characterization by UV-visible spectroscopy, Fourier transform infrared spectroscopy, x-ray diffraction, field-emission scanning electron microscopy, and atomic force microscopy. The biological evaluation was carried out with the help of agar well diffusion using *E. coli*, minimum inhibitory concentration, DPPH radical scavenging assay, reducing power activity, total antioxidant activity, and anticancer activity of silver nanoparticles (AgNPs) against Hep-G2 cancer cell lines. The average particle size of the synthesized nanoparticles was 35.50 ± 0.23 nm. The drug release kinetics was carried out to analyze the release of amoxicillin from the AgNPs. The present study clearly establishes the synthesis and the application of amoxicillin functionalized silver nanoparticles to be utilized as an important tool to fight against antibiotic-resistant bacterial strains.

Keywords Silver nanoparticles · Atomic force microscopy · X-ray diffraction · FTIR · FESEM

1 Introduction

Recent advances in biotechnology have accelerated the discovery of novel drug molecules. Metal-based nanoparticles possess several advantages over other systems, such as cell-specific targeting of the nanoparticle delivery system and the ability to control the kinetics of drug release [1]. There are developing requests for the synthesis of silver nanoparticles (AgNPs) utilizing green approaches because of their financially savvy and eco-accommodating nature [2]. These metal nanoparticles can be used in biomedical and industrial applications [3]. Launching innovative antibacterial nanomaterials and promising pharmacological strategies for the destruction of human bacterial infections that cause communicable diseases becomes more crucial, because diseases caused by antibiotic-resistant microorganisms have become more and more difficult to be effectively cured with available commercially antibiotics [4, 5].

Silver (I) oxide takes advantage of their low solubility in aqueous environments to slowly release silver ions as Ag $(OH)^{-2}$. It is well known that metallic silver is complexes by silver ions rendering silver clusters (Ag^{2+}, $Ag_4{}^{2+}$) [6]. Consequently, there is a need to produce virtuous, non-toxic, and environmentally friendly methods for the synthesis of AgNPs. The utilization of the biological system in this area is rapidly gaining importance due to its growing success.

Amoxicillin trihydrate (α-amino-hydroxybenzyl-penicillin) is a semi-synthetic, orally absorbed and broad-spectrum antibiotic. The monodispersed AgNPs with narrow particle size distribution were most effective antibacterial agents because of their high surface/volume fraction so that a large proportion of silver atoms were in direct contact with their environment [7–10]. Mousavi-Khattat et al. [11] had reported that the green synthesized silver nanoparticles had more desirable characteristics and biological activities compared to chemically synthesized nanoparticles. The narrow size range, spherical shape, high antioxidant, antibacterial, and DNA cleavage activities were seen in green nanoparticles. Also,

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