Chapter 6

Summary and Future scope

6.1 Summary

The thesis entitled “Functional nanomaterial based composites and their biomedical applications” has been divided into five chapters.

1. Introduction
2. Materials and Methods
3. Synthesis and in-vitro antibacterial behavior of curcumin conjugated gold nanoparticles
4. Bone tissue engineering application of 3-aminopropyltrimethoxysilane functionalized Au/Ag nanoparticles incorporated hydroxyapatite bioceramic
5. Multifunctional aspects of Clove essential oil functionalized gold nanoparticles: Antibacterial, antioxidant, anti-cancerous and biocompatibility

The important outcomes from the present study are as follows:

- AuNPs can be considered as astonishing molecular carriers for the targeting, intracellular trafficking and delivery of a wide range of biomolecules.
- Due to their physiochemical characteristics, they do not significantly cause cytotoxicity.
- Functionalization helps in improving the bioavailaity, hydrophilicity and stability of hydrophobic biomolecules.

- It also helps in densification of implant material, hence improve the mechanical properties.
- Demonstrate excellent antibacterial and antibiofilm activity via membrane depolarization, ROS generation, protein degradation etc.
- Accelerate cell adhesion and proliferation.

Chapter 1: This chapter opens with brief history of nanotechnology, followed by introduction about metal nanoparticles and gold nanoparticles. Various surface modification techniques of gold nanoparticles have also been discussed in the introductory chapter. Biomedical applications of these functionalized gold nanoparticles has discussed in detailed. Finally, the origin, motivation and work plan for the present thesis work is also discussed.

Chapter 2: This chapter elaborate the materials required and experimental details for synthesis of AuNPs, Cur-AuNPs, CEO-*f*AuNPs, Au/Ag NPs, HA and HA- xAu/Ag NPs composites. After that, the chapter discussed about various characterization techniques used to analyze the synthesized materials. Furthermore detailed methodology employed to evaluate antibacterial, antibiofilm, antioxidant, anti-cancerous and cytocompatibility application of these synthesized materials were discussed in detail.

Chapter 3: In this chapter, improved water dispersibility and stability of curcumin were studied through conjugation with gold nanoparticles. The successful synthesis of curcumin conjugated gold nanoparticles (Cur-AuNPs) was confirmed using X Ray Diffraction (XRD), Fourier transform infrared (FTIR) spectroscopy and UV vis absorbance. Transmission electron microscopy (TEM) revealed the average particle size of about 10-13 nm. The antibacterial characteristics in terms of Minimum inhibitory concentration (MIC) of Cur-AuNPs treatments were found to be lowest (8 µg/ml) than

AuNPs (32μg/ml) and Cur treatment (128 μg/ml). The quantitative analysis exhibited the superior antibacterial characteristics of Cur-AuNPs treated bacterial cells than untreated sample. In addition, curcumin conjugated AuNPs, produce more reactive oxygen species (60.0% cells population) and increased membrane permeability (65.3% cell population showed perturbed membrane acyl groups). Besides, biocompatibility of Cur-AuNPs was also assessed quantitatively and qualitatively. Statistical analyses revealed the augmented MG-63 cell proliferation in Cur-AuNPs than Cur & AuNPs treatment. Overall, Cur-AuNPs exhibited the enhanced antibacterial, antibiofilm characteristics and cytocompatibility.

Chapter 4: The present chapter discussed about fabrication of 3-aminopropyltrimethoxysilane functionalized gold (Au)-silver (Ag) nanoparticles incorporated in hydroxyapatite bioceramics. Incorporation of Au/Ag NPs helps to overcome the limitation (inadequate mechanical properties and bacterial susceptibility) associated with HA. Phase evolution, microstructural analysis and thermogravimetric analysis (TGA) were performed to understand the physical and chemical characteristics of the material. The maximum values of fracture toughness (0.89 MPa.m$^{1/2}$), hardness (6.87 GPa), compressive (125.62 MPa) and flexural strength (135.52 MPa) were measured for HA-10 Au/Ag NPs. Both quantitative and qualitative analyses of antibacterial behavior revealed that the adhesion of gram-positive (*S. aureus*) and gram-negative (*E. coli*) bacterial cells were reduced significantly after the incorporation of Au/Ag NPs as compared with the HA control. In addition, the effect of Au/Ag NPs incorporation on the cellular response was observed for the MG63 cell line. Both the quantitative and qualitative results reveal significantly enhanced cell proliferation with the incorporation of Au/Ag NPs as compared to HA. The addition of Au/Ag NPs in HA provides a material with appropriate mechanical, antibacterial, and cellular responses for further consideration.

Chapter 5: This chapter explores the multifunctional properties of Clove essential oil functionalized gold nanoparticles (CEO-*f*AuNPs) and their potential applications in various fields. TEM images demonstrate the spherical shaped particles with an average diameter of ~4.7 nm for AuNP while for CEO-*f*AuNP the particles size was increased to ~9.2 nm. The research investigates the antibacterial, antioxidant, anticancerous, and biocompatible properties of CEO-functionalized AuNPs. The study employs different characterization techniques to analyze the physicochemical properties of the nanoparticles. The results demonstrate the remarkable antibacterial activity of CEO-functionalized AuNPs against a range of bacterial strains with Minimum inhibitory concentration (MIC) 0.5 µg/ml. Additionally, the nanoparticles exhibit potent antioxidant effects (~94.0%), indicating their potential for combating oxidative stress-related disorders. Furthermore, the study reveals promising anticancer properties of CEO-functionalized AuNPs, exhibiting cytotoxic effects on cancer cells (Hela and MDA-MB-231; only 12-15% cells were live after CEO-*f*AuNP treatment) while preserving biocompatibility with normal cells (MG-63 and L929; approximetly 90-91% cells were live after CEO-*f*AuNP treatment). The multifunctional aspects of these nanoparticles offer significant potential for their utilization in various biomedical applications, including antibacterial agents, antioxidants, and anticancer therapies.

6.2 Future Scope

- Future research in the fields of synthetic chemistry for pharmaceutical development and the nano sciences will inevitably explicitly design new alterations in AuNPs surface to generate more robust and comprehensive treatments.

- We can also develop a conjugated nanomaterial that, when essential, stimulates a controlled release of these conjugates at the infection site.
- We may also consider implementing soluble biomolecules-AuNPs complexes that might be employed to encapsulate medical implants that are susceptible to secondary infections.
- We may also use these functionalized AuNPs in sensing of biomarkers.
- These can be utilized in field of anticancer drug designing.
- Can be used as fluorescent probe for bio-imaging applications.