Chapter-8

Summary and Conclusion

Natural products have played an important role in healthcare since the dawn of time, and they continue to be useful resource for the development of novel medicines. The interdisciplinary amalgamation of nanomaterial science and natural products may lead to their advanced pharmaceutical, biomedical and environmental applications. Carbon nanodots (CNDs) are fluorescent carbon nanomaterials with tunable fluorescence that range in size from 1 to 10 nm. CNDs exhibit tunable photoluminescence, biocompatibility, non-toxicity, and significant stability.

In this work, we fabricated Natural products-derived CNDs using a one-pot and eco-friendly hydrothermal method using *Andrographis paniculata*, *Asparagus racemosus*, and quercetin. The inherent properties and structure of these CNDs were characterized using High resolution-transmission electron microscopy (HR-TEM), X-ray photoelectron absorption spectroscopy (XPS), X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FT-IR), Selected area electron diffraction (SAED), Energy dispersive X-ray spectroscopy (EDAX), Raman spectroscopy, fluorescence spectroscopy, and absorption spectroscopy. Furthermore, thermal stability using Thermogravimetric analysis (TGA), photostability, and colloidal stability using the Zeta potential of CNDs were also determined. CNDs exhibited significant potential for sensing heavy metals such as As^{3+}, Ag^{+}, Fe^{3+}, and Hg^{2+}. These CNDs are developed for cellular imaging of cancerous cells, such as human breast cancer cells (MCF-7). CNDs exhibited antibacterial efficacy against clinically isolated multidrug-resistant organisms such as *Enterobacter cloacae* (G-), *Acinetobacter baumannii* (G-), *Escherichia coli* (G-), *Klebsiella pneumoniae* (G-), *Pseudomonas aeruginosa* (-), *Aeromonas hydrophila* (G-), *Staphylococcus aureus* (G+), *Enterococcus faecalis* (G+), and Methicillin-Resistant *Staphylococcus Aureus* (G+) and free radical scavenging potential (such as DPPH). We further tested the toxicity of these CNDs in Swiss albino mice and found that they were safe, as evidenced by biochemical, hematological, and histological parameters.

The fabrication of blue fluorescent CNDs from aqueous extract of *Andrographis paniculata* (AP), termed as AAPCDs, was accomplished using a simple and cost-effective one-pot hydrothermal method. Apart from free radical sensing and scavenging capabilities, the AAPCDs are developed to have cellular imaging of human breast cancer cells (MCF-7). AAPCDs demonstrated negligible cytotoxicity towards multi drug resistant clinically isolated strains of gram positive and gram negative bacteria such as *Staphylococcus aureus* (G+) and *Klebsiella pneumonia* (G-), suggesting that they could be used in microbiology for bioimaging research. We've also shown that AAPCDs can be used as a nano-probe for sensing Fe^{3+}. We further tested the toxicity of these CNDs in swiss albino mice, and found that they were safe, as evidenced by biochemical, haematological, and histological parameters.

The fabrication of pink fluorescent CNDs from ethanolic extract of AP, termed as EAPCDs, was accomplished using a simple and eco-friendly one-pot hydrothermal method. EAPCDs had a distinct pink fluorescence that was unique in comparison to earlier reported studies. They exhibited anti-bacterial properties against clinically isolated bacterial strains such as *Staphylococcus aureus* (G+) and *Klebsiella pneumonia*

(G-) and demonstrated free radical (such as DPPH) sensing and scavenging qualities. EAPCDs were designed for MCF-7 breast cancer cell bioimaging. EAPCDs have also been used as a nano-probe to detect Hg^{2+}. We further tested the toxicity of these CNDs in Swiss albino mice, and found that they had negligible toxicity as evidenced by biochemical, haematological, and histological parameters.

A simple one-pot hydrothermal method was used to fabricate bluish-green fluorescent CNDs from *Asparagus racemosus*, termed as ARCD. Surface passivation of ARCD with a 1:1 ratio of carrageenan (CAR) and polyethylenimine (PEI), termed ARCCD, enhanced the fluorescence quantum yield even further. The utility of ARCD and ARCCD as a nano-probe for sensing As^{3+} and Ag^{+} has been demonstrated in this study. These CNDs exhibited inhibitory effect on cell proliferation against breast (MDA-MB-231) and cervical (SiHa) cancer cells. In addition, no substantial cytotoxicity was seen in Normal Kidney (HEK 293) cells, implying that the produced CNDs are cancer specific. CNDs exhibited antibacterial efficacy against clinically isolated multidrug-resistant organisms as well as free radical scavenging potential. We further tested the toxicity of these CNDs in Swiss albino mice, and found that they had negligible toxicity as evidenced by biochemical, haematological, and histological parameters.

A one-pot hydrothermal method was utilised to fabricate quercetin-derived CNDs for various biomedical and environmental applications. The qCD was employed as a fluorescent nano-probe that can detect As^{3+} concentrations through enhancement in fluorescence emission, possibly due to intramolecular rotation restriction, which may be activated by atypical qCD-As^{3+} interactions. The effect of surface fabrication of polyethylene glycol (Pg) on the ability of qCD for metal sensing was also evaluated, and it was observed that upon surface fabrication with Pg, qCD-Pg lost its ability to sense As^{3+} selectively but was able to detect Fe^{3+} concentrations selectively. Secondly, qCD-Pg acted as an andrographolide (Ad) nano-carrier via electrostatic interactions. These conjugates can prolong and improve the drug release, leading to an enhanced killing effect on leukemia cancer cells (K-562). Also, the qCD-Pg-Ad complex had a better anticancer effect on K-562 than free Ad but very low cytotoxicity to normal kidney cells (Vero), indicating specificity of the conjugate to the Leukemia cancer. Further, these nanodots considerably inhibited multi drug resistant bacterial strains' growth and exhibited significant free radical scavenging potential. These nanodots were also evaluated for thermal stability, colloidal dispersion stability, and photostability.

The plants in these studies were chosen based on our preliminary experiments involving numerous plants and various parameters such as quantum yield, size, optical-physical properties of carbon nanodots were taken into consideration for finalizing the plants. Other plant materials such as *Silybum marianum*, *Sansevieria roxburghii*, etc derived CNDs were not used for further studies as they didn't exhibit strong fluorescence and the quantum yield was comparatively lower. Overall we observed that *Andrographis paniculata*-derived CNDs had better bioimaging potential, *Asparagus racemosus* derived CNDs had better metal sensing potential and Quercetin-derived CNDs has better drug loading capacities as comparison to other CNDs. The chemical diversity of these precursors would have imparted differencing photo-physical attributes to their derived CNDs.

The findings of the present study demonstrate natural products-derived CNDs as a smart nano-probes with wide utility in pharmaceutical, biomedical and environmental applications. It provides the future roadmap for the utilization of such natural products-derived CNDs in newly emerging challenges of the 21^{st} century.