
Summary and Conclusion

The present research focused on the development of eco-friendly bioactive nanoparticle-encapsulated formulations for sustained drug delivery and *in vitro* biomedical applications. Allicin, a major bioactive compound in garlic, is known for its therapeutic potential but limited by instability, low yield, poor bioavailability, and rapid degradation by heat. To address this, the ionic liquid-based extraction was utilised, which significantly improving the extraction efficiency compared to conventional organic solvents.

To enhance Allicin's stability and therapeutic utility, floating tablets and microsphere-based formulations were developed for sustained drug release. Further, to improve the enhanced efficiency of metabolites, we have utilised eco-friendly synthesised gold and silver nanoparticles. This approach avoids the environmental hazards of chemical synthesis by plant-derived phytochemicals as bioreductants.

A systematic literature review was carried out to understand the existing state of research. Based on the review, the selected plants such as *Amphilophium paniculatum* (leaf), *Tristellateia australasiae* (leaf), *Haematocarpus validus* (fruit), and *Phoenix dactylifera* (seed) were selected. It was observed that these plant materials have not previously been explored for the eco-friendly synthesis of gold and silver nanoparticles and their biomedical applications.

In silico molecular docking identified selected bioactive compounds as potential DPP-IV inhibitors, for managing Type 2 diabetes. The synthesised nanoparticles exhibited potent antioxidant, antibacterial, anticancer, and antidiabetic activities, validated through *in vitro* assays.

To further enhance therapeutic efficacy, both garlic-nanoencapsulated microspheres and nanodrug encapsulated microspheres were developed, effectively improving the stability, bioavailability and sustained release. In addition, the silver nanoparticles and their nanocomposites were successfully used as a coating agent on woven fabrics, resulting in enhanced antimicrobial efficacy and UV-protective fabrics.

The summarized results drawn from the present research work are detailed below:

- ❖ Ionic liquid-based extraction of bioactive compound from garlic yielded relatively higher extraction efficiency (86%) than methanol (34%).
- ❖ Optimised floating tablet formulation (18RF) containing drug, beeswax, lactose, PVP, stearic acid, sodium bicarbonate, and cellulose acetate, achieved 99% sustained drug release over 120 h in 0.1N HCl. The novelty lies in the specific combination and extended-release profile which is not reported in literature.
- ❖ Optimised blank microsphere formulation (MS1) was further incorporated with either the drug (MMS1) or a garlic bioactive compounds (MS1G) using solvent evaporation method.
- ❖ FESEM analysis revealed spherical microspheres with average sizes of 4.9 μm for MMS1 and 10.4 μm for MS1G.
- ❖ Microspheres encapsulating fresh garlic juice exhibited 85-91% antibacterial activity against Gram-positive bacteria and over 95% activity against Gram-negative bacteria, compared to the commercial standard.
- ❖ Garlic-encapsulated microspheres (MS1G) showed 89.02% release of garlic bioactive compounds over 120 h.
- ❖ Phytochemical screening of selected plants confirmed the presence of secondary metabolites such as alkaloids, flavonoids, terpenoids, saponins, carbohydrates, glycosides, polyphenols, tannins, anthraquinones, anthocyanins, quinones, lignins, coumarins, and volatile oil. These bioactive constituents act as bioreductants during nanoparticle synthesis.
- ❖ Eco-friendly synthesis of gold nanoparticles (GNPs) was achieved using room temperature and solar light irradiation methods. Solar light irradiation resulted in faster synthesis and environmental compatibility.
- ❖ Using solar light irradiation, GNPs formed rapidly: APEG (48 s), TAEG (5 min), BFEG (4 min) and DSEG (30 s), compared to 1-45 min under room temperature conditions.
- ❖ Silver nanoparticles (SNPs) synthesised via solar light irradiation method also showed rapid formation: APES (40 s), TAES (1 min), BFES (4 min) and DSES (2 min).
- ❖ UV visible spectroscopy showed characteristic surface plasmon resonance bands at 520-550 nm for GNPs and 420-450 nm for SNPs, confirming nanoparticle formation.
- ❖ XRD patterns confirmed the crystalline nature of the synthesised GNPs and SNPs.
- ❖ Zeta potential analysis validated the good NPs stability with values ranging from -34 mV to -38.4 mV for GNPs and -32.0 mV to -43.3 mV for SNPs.

- ❖ FESEM imaging confirmed spherical morphologies: GNPs (12-20 nm) and SNPs (26-33 nm).
- ❖ *In silico* analysis revealed strong interaction between the identified bioactive compounds with the target receptor, along with drug like, acceptable pharmacokinetic, and toxicity properties.
- ❖ Antioxidant studies showed both GNPs and SNPs effectively inhibited free radicals; SNPs exhibited higher inhibition (72% to 92%) compared to GNPs (54% to 77%).
- ❖ *K. pneumoniae* clinical isolates exhibited 87% resistance to APES NPs as compared to the standard drug. This study presents the first report on the antibacterial activity of APE, TAE and BFE extracts and their respective GNPs and SNPs.
- ❖ *Allium cepa* bioassay results showed dose dependent increases in cell division for both plant extracts and metallic NPs.
- ❖ APES NPs reduced A⁵⁴⁹ lung cancer cell viability by 35% at 200 µg/mL, compared to 13.8% inhibition by the standard etoposide.
- ❖ Both silver and gold nanoparticles exhibited significant antidiabetic activity, with silver nanoparticles showing the highest α -amylase inhibition at 100 µg/mL.
- ❖ Nano drug (MMS1AS and MMS1DG) and garlic-nano (MS1G2 and MS1G2S) encapsulated microspheres were prepared *via* solvent evaporation method. FESEM images of nano drug loaded microspheres confirmed spherical morphology with average particle sizes of 0.18 µm (MMS1AS) and 0.35 µm (MMS1DG).
- ❖ FESEM images of garlic-nano encapsulated microspheres confirmed spherical microspheres with average diameter of 6.6 µm (MS1G2) and 6.8 µm (MS1G2S).
- ❖ EDS mapping confirmed the presence of Ag, and Au in both nano drug and garlic-nano encapsulated microspheres.
- ❖ Garlic-nano encapsulated microspheres exhibited strong antibacterial activity, producing ZOI of 17-19 mm, compared to the standard available in the market.
- ❖ α -amylase inhibitory activity of garlic-nano encapsulated microspheres exhibited dose-dependent inhibition of 89.3%, as compared to standard.
- ❖ Nano drug and garlic-nano encapsulated microspheres exhibited sustained release profiles, achieving 95-97% drug release over 120 h.
- ❖ Ball-milled red sandal wood powder dyed cotton fabric significantly improved UV-protection (UPF 329).
- ❖ SNPs and nanocomposite coatings applied on woven fabrics showed excellent antimicrobial activity.