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Synthesis Of Ironoxide Nanoparticles From Punica Granatum Peels And Formulation Of Nanobeads For Effective Drug Delivery Application

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Abstract- This project focuses on the eco-friendly synthesis of iron oxide nanoparticles using Punica granatum peels and their application in advanced drug delivery systems through nanobead formulation. In recent years, nanotechnology has emerged as a powerful tool in biomedical engineering, particularly in improving drug delivery efficiency and reducing side effects. Conventional methods for nanoparticle synthesis involve toxic chemicals, high energy consumption, and environmental hazards. To overcome these limitations, green synthesis using plant-based materials has gained significant attention. Pomegranate peels are rich in bioactive compounds such as polyphenols, flavonoids, and tannins, which act as natural reducing and stabilizing agents in nanoparticle formation. In this study, iron oxide nanoparticles were synthesized using aqueous peel extract and further characterized using UV-Visible spectroscopy and FTIR (Fourier Transform Infrared Spectroscopy) analysis to confirm their formation and functional groups. The synthesized nanoparticles were then incorporated into polymer-based nanobeads using biocompatible materials such as alginate or chitosan. These nanobeads were used as carriers for drug delivery, enabling controlled and sustained release of therapeutic agents. The results demonstrate enhanced drug loading efficiency, improved stability, and reduced toxicity compared to conventional delivery methods. Overall, this project highlights the potential of green nanotechnology in developing safe, cost-effective, and efficient drug delivery systems for biomedical applications.

Keywords- Iron oxide nanoparticles, green synthesis, Punica granatum, Nano beads, drug delivery, controlled release, biomedical engineering.

I. INTRODUCTION

The use of nanoparticles in medicine, particularly for drug delivery, has expanded significantly due to their unique properties, including high surface area and the ability to encapsulate and transport therapeutic agents. However, many conventional methods for nanoparticle synthesis use toxic chemicals and require high energy consumption, making them environmentally unfriendly. Therefore, there is a growing interest in developing "green" and sustainable alternatives, such as those that use natural materials as reducing and stabilizing agents. Punica granatum (pomegranate) peels are a rich source of bioactive compounds, including phenolic compounds, that have been shown to effectively reduce metal ions into nanoparticles. This study aims to develop Ag/Fe nanoparticles using a green synthesis method, utilizing the waste product of pomegranate peels. The combination of silver (Ag) and iron (Fe) nanoparticles in a single system offers synergistic potential for drug delivery applications. For example, AgNPs possess antibacterial properties, while iron nanoparticles (FeNPs) can be manipulated using magnetic fields. By combining them into a single Ag/Fe nanoparticle, the goal is to create a multifunctional nanomaterial with enhanced capabilities for drug targeting and delivery.

This research focuses on the sustainable and eco-friendly synthesis of Ag/Fe nanoparticles from

Punica granatum peels and their characterization. The resulting nanoparticles will be evaluated for their potential as a novel platform for drug delivery, contributing to both waste management and the development of advanced nanomedicines.

II. METHOD

1. Collection and Preparation of Plant Material
Fresh peels of Punica granatum were collected and thoroughly washed with distilled water to remove dust and impurities. The cleaned peels were dried under sunlight for several days until complete moisture removal.

The dried peels were then ground into fine powder using a mechanical grinder. Approximately measured quantity of the powder was boiled in distilled water at 60–80°C for 20–30 minutes to extract bioactive compounds. The extract was filtered using Whatman filter paper and stored at 4°C for further use.

2. Preparation of Iron Salt Solution
Iron salt solutions such as Ferric Chloride ($FeCl_3$) and Ferrous Sulphate ($FeSO_4$) were prepared in distilled water at required molar concentrations. These solutions act as precursors for iron oxide nanoparticle synthesis.
The solution was stirred continuously using a magnetic stirrer to ensure complete dissolution and homogeneity.

3. Green Synthesis of Iron Oxide Nanoparticles
The prepared pomegranate peel extract was added dropwise into the iron salt solution under constant stirring. The reaction mixture was maintained at controlled temperature and pH conditions.

During the reaction, a visible color change (light brown to dark brown/black) was observed, indicating the formation of iron oxide nanoparticles. The phytochemicals present in the extract act as reducing agents to convert Fe^{2+}/Fe^{3+} ions into nanoparticles and also stabilize them.

4. Purification and Collection of Nanoparticles
The synthesized nanoparticles were separated using centrifugation at high speed (e.g., 8000–10000 rpm for 10–15 minutes). The supernatant was discarded, and the pellet was washed multiple times with distilled water and ethanol to remove impurities and unreacted substances.

The purified nanoparticles were then dried in a hot air oven at around 50–60°C and stored for further analysis.

5. Characterization of Nanoparticles
🔬 UV-Visible Spectroscopy
Used to confirm nanoparticle formation by analyzing absorption peaks.

🔬 FTIR (Fourier Transform Infrared Spectroscopy)
Used to identify functional groups present on the nanoparticle surface and confirm the role of phytochemicals in reduction and stabilization.

6. Preparation of Polymer Solution
Biocompatible polymers such as sodium alginate or chitosan were used for nanobead formulation. The polymer was dissolved in distilled water under continuous stirring to obtain a homogeneous viscous solution.

Cross-linking agents (e.g., calcium chloride for alginate) were prepared separately.

7. Formation of Nanobeads
The synthesized iron oxide nanoparticles were mixed with the polymer solution. This mixture was then added dropwise into the cross-linking solution using a syringe.

Instant gelation occurs, leading to the formation of spherical nanobeads. The beads were allowed to stabilize for a specific duration and then collected and washed.

8. Drug Loading Process
The prepared nanobeads were immersed in a drug solution and allowed to absorb the drug molecules. The drug loading efficiency was calculated by

measuring the concentration difference before and after loading.

This ensures that the nanobeads act as effective carriers for drug delivery.

9. In-vitro Drug Release Study

Drug-loaded nanobeads were placed in a simulated biological medium (e.g., phosphate buffer solution). Samples were taken at regular intervals to measure the amount of drug released.

This study helps in understanding the controlled and sustained release behavior of the nanobead system.

10. Data Analysis

The obtained results were analyzed using graphs and statistical methods. Drug release profiles, efficiency, and stability were evaluated to determine the performance of the developed system.

III. RESULT

The present study successfully demonstrated the green synthesis of iron oxide nanoparticles using Punica granatum peel extract, which served as an efficient natural reducing and stabilizing agent. The synthesis process was initially confirmed by a distinct color change from light brown to dark brown/black, indicating the formation of nanoparticles. Further confirmation was obtained through UV-Visible spectroscopy, which showed characteristic absorption peaks corresponding to iron oxide nanoparticles. In addition, FTIR (Fourier Transform Infrared Spectroscopy) analysis revealed the presence of functional groups such as hydroxyl (–OH), carbonyl (C=O), and other bioactive compounds, confirming the involvement of phytochemicals in the reduction and stabilization process. The synthesized nanoparticles were successfully incorporated into biocompatible polymer matrices to form nanobeads, which were visually observed as stable, well-formed, and uniformly distributed structures, as evidenced in Fig.

The nanobeads maintained their structural integrity without any visible aggregation or deformation, indicating effective cross-linking and stability. Furthermore, the nanobead system exhibited high drug loading efficiency, suggesting its capability to effectively encapsulate therapeutic agents. The in-vitro drug release studies demonstrated an initial controlled release followed by a sustained release pattern over time, which is highly desirable for maintaining consistent drug concentration in the body. This controlled release behavior reduces the frequency of drug administration and minimizes potential side effects. Additionally, the nanobead formulation showed good physical stability under experimental conditions, with no significant degradation observed. Overall, the results confirm that the developed system is efficient, eco-friendly, and suitable for advanced drug delivery applications, offering improved performance compared to conventional drug delivery methods.

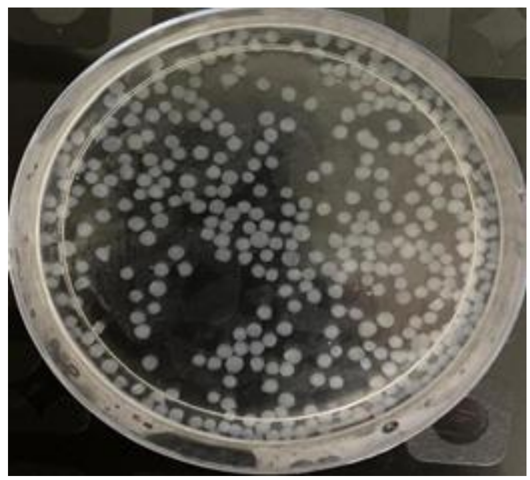

Fig:1 Polymer Beads Encapsulated With Iron Oxide Nanoparticles For Targeted Drug Delivery

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