Formulation and Evaluation of Methotrexate-loaded Polymeric Nanoparticles in Breast Cancer Treatment

Thesis submitted in partial fulfilment

For the Award of Degree

Doctor of Philosophy

BY

RINKI VERMA

SCHOOL OF BIOMEDICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY BHU, VARANASI, 221005, U.P., INDIA

Roll No. 18021005

2023

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It is further certified that **Rinki Verma** has fulfilled all the Comprehensive Examination, Candidacy, and SOTA requirements for the award of Ph.D. Degree.

Dr. Manoj Kumar
(Supervisor)

Department of Chemical Engineering & Technology,
Indian Institute of Technology,
Banaras Hindu University
Varanasi-221005, India

Dr. MANOJ KUMAR
Associate Professor
Department of Chemical Engg. & Techn.
IIT (BHU), Varanasi-221005

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Place: IIT (BHU), Varanasi

Rinki Verma

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It is certified that the above statements made by the students are correct to the best of my knowledge.

Dr. Manoj Kumar
(Supervisor)

Department of Chemical Engineering & Technology,
Indian Institute of Technology,
Banaras Hindu University
Varanasi-221005, India

DR. MANOJ KUMAR
Associate Professor
Department of Chemical Engg. & Techn.
IIT (BHU), Varanasi-221005

Signature 11/07/23

Coordinator of the School

समन्वयक/CO-ORDINATOR
जैव चिकित्सा अभियांत्रिकी स्कूल
SCHOOL OF BIOMEDICAL ENG
भारतीय प्रौद्योगिकी संस्थान (का.हि.
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ABBREVIATION

ANOVA	One-way Analysis of Variance
AUC	Area under the concentration-time curve
ALP	Alkaline Phosphate
BSC	Biopharmaceutical Classification System
BSA	Bovine Serum Albumin
BC	Breast Cancer
CS	Chitosan
CS-NPs	Chitosan Nanoparticles
C_{max}	Maximum plasma concentration
CL	Plasma Clearance
DOE	Design of Experiments
DL	Drug Loading
DMSO	Dimethyl Sulfoxide
DMEM	Dulbecco Modified Eagle Medium
DMBA	7,12-Dimethylbenz[a]anthracene
DLS	Dynamic Light Scattering
EE	Entrapment Efficiency
ELISA	Enzyme-Linked Immunosorbent Assays
ER	Estrogen Receptor
FTIR	Fourier Transform Infrared Spectroscopy
FBS	Fetal Bovine Serum
HR-TEM	High-Resolution Transmission Electron Microscopy
HPLC	High-Performance Liquid Chromatography
HER-2	Human Epidermal Growth Factor Receptor 2
IVIS	In-vivo Fluorescent Imaging
IL	Interleukins
IHC	Immunohistochemistry
i.p	Intraperitoneally injection
i.v	Intravenous injection
KBr	Potassium Bromide
MTX	Methotrexate

MTT	3-(4, 5-dimethylthiazol-2-yl)-2,5 diphenyl tetrazolium bromide
MRT	Mean Residence Time
NMU/MNU	N-methyl N-nitrosourea
NPs	Nanoparticles
PBS	Phosphate buffer solution
PDI	Polydispersive Index
PK	Pharmacokinetic
P/CL	Polymer/cross-linker ratio
PR	Progesterone Receptor
RSM	Response Surface Methodology
RT	Reaction Time
SAED	Selected Area Electron Diffraction
SEM	Scanning Electron Microscope
s.d	Standard deviation
S/N ratio	Signal-to-Noise ratio
SD	Sprague Dawley
STPP	Sodium tripolyphosphate
SGOT/ALT	Serum Glutamic Oxaloacetic Transaminase
SGPT/AST	Serum Glutamic Pyruvic Transaminase
$t_{1/2}$	Plasma half-life
TNBC	Triple Negative Breast Cancer
TNF-α	Tumor Necrosis Factor-α
TGA	Thermogravimetric Analysis
Vd	Volume of distribution
XRD	X-Ray Diffraction

PREFACE

We successfully synthesized methotrexate-loaded chitosan nanoparticles in this study using the ionic gelation method. Taguchi design was employed to optimize formulation parameters such as particle size, entrapment efficiency, and drug loading capacity. The nanoparticles were designed to improve therapeutic efficacy and minimize the side effects of methotrexate in breast cancer treatment. Additionally, we developed a self-targeted formulation by modifying reaction conditions. Also, we synthesized fluorescent calcium carbonate nanoparticles functionalized with chitosan and loaded them with methotrexate for controlled drug delivery. The nanoparticles were extensively characterized using various techniques, including UV-vis spectrophotometry, HPLC, DLS, FTIR, XRD, SAED, fluorescence spectrophotometry, IVIS, and biochemical analysis. The nanoparticles exhibited spherical morphology and demonstrated good biocompatibility and anticancer effects. They effectively reduced cytokine levels and showed high potential for triple-negative breast cancer treatment. The optimized nanoparticles had desirable physicochemical properties, controlled drug release, and improved pharmacokinetic profiles compared to free methotrexate. They exhibited biocompatibility, minimal hemolysis, and higher cytotoxicity against breast cancer cells. In a chemically-induced breast cancer rat model, the nanoparticles significantly inhibited tumor growth compared to free methotrexate. These findings highlight the potential of the developed nanoparticles for breast cancer treatment, offering enhanced drug delivery, improved pharmacokinetics, and reduced toxicity. The functionalized fluorescent nanoparticles also demonstrated biocompatibility, bioimaging capabilities, and anticancer activity. This study provides a promising therapeutic approach with the potential for clinical translation in the future. The thesis work has been conceptualized considering the above-discussed aspects of biocompatible nanocarrier research for breast

cancer treatment. The thesis consists of seven chapters, with the first two devoted to the introduction, literature review & the objective of the work section. Four out of the remaining five chapters extensively discussed different aspects of prepared nanoparticles and their application in breast cancer treatment. The last chapter belongs to the summary of the overall research.

The present study is divided into the following chapters.

Chapter 1: This chapter provides an in-depth exploration of cancer, including its various types, prevalence, and the urgent need for effective treatment strategies. It highlights the wide-ranging prospects of nanoparticles in the context of breast cancer treatment, emphasizing their potential to revolutionize current therapeutic approaches. The chapter delves into the crucial considerations involved in material selection for nanoparticle synthesis, considering the desired properties and characteristics necessary for effective drug delivery. Furthermore, it discusses the adopted technologies employed during the synthesis of nanoparticles, focusing on the ionic gelation method and its advantages. Special emphasis is given to the superiority of polymeric nanoparticles and inorganic nanomaterials, discussing the unique properties that make them ideal candidates for targeted drug delivery and enhanced therapeutic outcomes in breast cancer treatment.

Chapter 2: In this chapter, exploring the comprehensive review critically examines the potential of Methotrexate-loaded or encapsulated chitosan-based nanoparticles for breast cancer treatment. It covers various aspects, including synthesis techniques, physicochemical characterization, drug release kinetics, cellular uptake mechanisms, and strategies to enhance therapeutic efficacy. This comprehensive analysis serves as a foundation for further research and development in the field of chitosan-based nanoparticle formulations for breast cancer therapy.

Chapter 3: This chapter focuses on synthesizing a 1-hour-methotrexate-encapsulated polymeric nanocarrier using the ionic gelation method. The formulation is optimized using Taguchi design, a Design of Experiment (DOE) approach, to enhance its effectiveness in improving therapeutic efficacy while minimizing the side effects of the drug. The chapter delves into the details of the synthesis process, discussing the specific parameters and conditions employed to achieve the desired nanocarrier formulation. To ensure the reliability and quality of the nanocarrier, a comprehensive characterization is conducted using various microscopy and spectroscopy techniques. Furthermore, the chapter addresses the crucial aspect of assessing the toxicity of the nanocarrier. To evaluate its safety, a toxicity study is conducted in normal rats, with the evaluation focusing on tissue histopathology analysis.

Chapter 4: This chapter focuses on formulating a single-step self-assembly 3-hour-methotrexate-encapsulated polymeric nanocarrier that exhibits pH-sensitive drug release specifically designed for the breast cancer microenvironment. To evaluate the anticancer efficacy of the nanoparticles, a chemically induced N-methyl-N-nitrosourea (NMU) breast tumor rat model is developed. Furthermore, the assessment includes evaluating tumor volume, tumor weight, and other relevant parameters to determine the therapeutic impact of the nanoparticles on breast cancer.

Chapter 5: This chapter described the histopathological and biochemical assessment using a developed nano-formulation chemically N-methyl-N-nitrosourea (NMU) induced breast tumor rat model. Histopathology was done for tumor tissue, Kidney, and liver to check any toxicity of nanoparticles. Nano-formulation intravenous administrated in tumor-bearing rats, liver and kidney biomarker analysis was done. And different pro-inflammatory cytokines such as TNF-α, IL-1β, and IL-6 were also checked for tumor generation confirmation and treatment efficacy.

Chapter 6: This chapter focuses on synthesizing chitosan-functionalized luminescent calcium carbonate nanoparticles (@Cal-CS-MTX-Nps) as a carrier for methotrexate and uses it for bioimage and treatment in breast tumor-bearing rats. The nanoparticles were characterized by various spectroscopy and microscopy techniques. The anticancer efficacy of nanoparticles was assessed in DMBA (dimethylbenz (a) anthracene) induced breast tumor rat model.

Chapter 7: The final chapter summarizes the overall research findings and provides conclusions regarding the development and application of methotrexate-loaded chitosan nanoparticles for breast cancer treatment.