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RESEARCH ARTICLE

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DEVELOPMENT AND EVALUATION OF A PHYTOCHEMICAL-BASED NANOCARRIER FOR BREAST CANCER TREATMENT

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ABSTRACT: Breast cancer is among the most prevalent forms of cancer affecting women globally, and despite advances in chemotherapy, side effects from non-specific treatment remain a major concern. In this study, a nanocarrier formulation was developed using curcumin, a naturally derived compound with established anticancer activity. The curcumin was encapsulated within PLGA nanoparticles to address limitations like poor solubility and limited bioavailability. The resulting particles were evaluated for size, surface charge, drug-loading efficiency, and release kinetics. When tested against MCF-7 breast cancer cells, the nanoformulation showed enhanced cytotoxicity and uptake compared to free curcumin. These findings highlight the potential of phytochemical-based nanocarriers as a more focused and safer approach to breast cancer therapy.

Keywords: Breast cancer, Curcumin, Nanocarrier, PLGA nanoparticles, Targeted drug delivery, MCF-7 cells, Phytochemicals

INTRODUCTION

Breast cancer continues to be a leading health challenge worldwide, particularly among women. Although advancements in diagnostic tools and chemotherapy have improved treatment outcomes, the non-selective nature of many anticancer drugs still causes serious side effects [1]. These include damage to healthy cells, which often leads to complications like fatigue, hair loss, and lowered immunity. For many patients, such effects not only diminish quality of life but may also interfere with consistent treatment adherence [2]. As the medical community continues to seek safer treatment strategies, attention has increasingly turned toward plant-derived compounds. The natural substance curcumin which scientists extract from the turmeric root (*Curcuma longa*) behaves as a compound. Scientific authorities recognize turmeric root extract curcumin as an effective anti-inflammatory agent but also understand it demonstrates cancer-fighting properties [3]. Research studies demonstrate curcumin functions in slowing cancer growth while initiating programmed cell demise and blocking capillary development to isolated cancer cells. The medical implementation of curcumin faces substantial restrictions in practice. Its poor water solubility and rapid degradation in the body hinder its absorption and therapeutic effectiveness [4].

The development of nanotechnology shows great potential to improve the current methods of treatment. Research scientists utilize biodegradable polymer-based nanoparticles to integrate curcumin which improves its chemical robustness and enables targeted delivery to cancer cells. PLGA (poly lactic-co-glycolic acid) represents a widely investigated biodegradable material because of its secure properties alongside controlled drug release capabilities during a specific time period [5].

The scientists aim to develop a nanocarrier system from PLGA polymers loaded with curcumin which they will evaluate regarding its physical aspects and biological outcomes against breast cancer MCF-7 cells. The combination of natural compounds and state-of-the-art drug delivery technology creates an improved cancer treatment option because it maintains therapeutic value and guarantees precise delivery while minimizing adverse effects in patients [6].

MATERIALS AND METHODS

Materials

The researchers selected curcumin with minimum 94% purity as their primary plant-based encasing agent for this study. A reliable supplier in biochemical substances provided the curcumin material. Toward the delivery of these nanoparticles scientists selected poly(lactic-co-glycolic acid) (PLGA) that functions as an established biodegradable and biocompatible polymer [7]. Emulsion stability during preparation required the usage of polyvinyl alcohol (PVA) as the selected surfactant. The human breast cancer cell line MCF-7 obtained from a recognized cell culture repository served for *in vitro* evaluations. Analytical-grade chemicals served as the main materials throughout the research without further purification [8].

Preparation of Curcumin-Loaded Nanoparticles

Manufacturing of nanoparticles occurred by implementing the emulsion–solvent evaporation technique. In this process, specific quantities of PLGA and curcumin were dissolved in an organic solvent, such as dichloromethane, to create the oil phase of the emulsion. This solution was then slowly added to an aqueous solution of PVA under high-speed homogenization to create an oil-in-water emulsion. With continuous stirring, the organic solvent was evaporated, leading to the formation of nanoparticles. The resulting particles were collected by centrifugation, thoroughly washed with distilled water to remove any unbound substances, and then freeze-dried for storage [9].

Characterization of Nanoparticles

To evaluate the quality and consistency of the nanoparticle formulation, several parameters were analyzed:

- **Particle Size and Surface Charge:** These were determined using dynamic light scattering (DLS), providing insights into average size and zeta potential [10].
- **Surface Morphology:** The shape and structure of the nanoparticles were examined using either scanning electron microscopy (SEM) or transmission electron microscopy (TEM) [11].
- **Drug Loading and Encapsulation Efficiency:** These were measured using UV-visible spectrophotometry by comparing the total and unencapsulated drug content in the formulation [12].
- ***In Vitro* Drug Release:** Nanoparticles were suspended in phosphate-buffered saline (PBS, pH 7.4), and samples were collected at various time points to track curcumin release over 48 hours [13].

Biological Evaluation
Cytotoxicity (MTT Assay)

The anticancer potential of the nanoparticle formulation was assessed through MTT assay. MCF-7 cells were exposed to both free curcumin and curcumin-loaded nanoparticles. After 48 hours of treatment, cell viability was determined by measuring the absorbance of formazan crystals formed in viable cells [14].

Cellular Uptake

To observe how effectively the nanoparticles entered cancer cells, curcumin's natural fluorescence was used as a marker. Cells treated with the nanoparticle formulation were examined under a fluorescence microscope to assess internalization [15].

RESULTS
Nanoparticle Properties

The curcumin-loaded nanoparticles exhibited an average particle size of 165 ± 10 nm, which is suitable for tumor targeting through passive diffusion. The zeta potential of the nanoparticles was found to be −24.3 mV, reflecting strong electrostatic repulsion, which helps keep the particles well-dispersed and prevents premature clumping. Regarding drug incorporation, the formulation demonstrated an encapsulation efficiency of 72.4%, along with a drug loading of 14.8%. These values confirm that a substantial amount of curcumin was effectively entrapped within the PLGA matrix during the preparation process.

Table 1: Physicochemical Properties of Curcumin-Loaded PLGA Nanoparticles

Parameter	*Curcumin-Loaded PLGA Nanoparticles*
Particle Size (nm)	165 ± 10
Zeta Potential (mV)	−24.3
Encapsulation Efficiency (%)	72.4
Drug Loading (%)	14.8

Drug Release Behavior

The nanoparticle formulation released curcumin into solution during the 48-hour experimental duration. The first 20% of drug release occurred quickly from the nanoparticle surface as a result of loosely bound curcumin. The formulation released its material content in a two-part process that began with an initial fast burst but eventually achieved approximately 85% release at the end of the testing period. The formulation demonstrates constant curcumin delivery throughout a time period which could help minimize the number of required therapeutic doses.

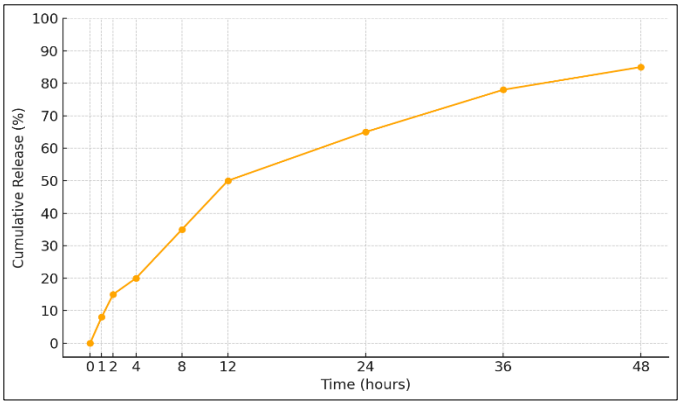

Fig. 1: Cumulative release of curcumin (%) from PLGA nanoparticles over 48 hours in PBS (pH 7.4).

Anti-Cancer Activity (MTT Assay)

Both free curcumin and its encapsulated form via nanoparticles were analyzed for anticancer action against MCF-7 breast cancer cells. An MTT assay revealed that nanocurcumin caused greater toxicity towards cell viability and outperformed unstructured free drug cells.

- Free curcumin (20 µg/mL) reduced viability to 62%
- Nano-curcumin (20 µg/mL) reduced it further to 35%
- Untreated control cells maintained 100% viability

Curcumin achieves enhanced cancer cell-targeting capabilities when it is given through nanoparticle delivery systems.

Table 2: Cell viability (%) in response to different treatments (48-hour exposure)

Treatment	*Cell Viability (%)*
Control (Untreated)	100
Free Curcumin (20 µg/mL)	62
Nano-Curcumin (20 µg/mL)	35

Intracellular Uptake Observation

The fluorescence properties of curcumin in natural form allowed researchers to study nanoparticle uptake within MCF-7 cells by using fluorescence microscopy. Nanoparticle-containing cells showed intensified fluorescence which spread uniformly compared to the free curcumin-treated cells indicating superior drug uptake and retention behavior.

DISCUSSION

The research results show that curcumin treatment within PLGA nanoparticles makes this therapeutic approach more practical for treating breast cancer. The main advantageous characteristic included the uniform nanoparticles measuring 165 nm in size which represents an optimal dimension for tumor tissue accumulation through EPR effect enhancement. This specific size range of nanoparticles shows strong accumulation properties in cancerous areas because tumor vasculature is porous therefore known as the enhanced permeability and retention (EPR) effect.

The formulation stayed stable because of the negative surface charge (zeta potential of –24.3 mV) which also enhanced its ability to disperse in biological solutions while preventing particle clumping during storage. Equally important were the high encapsulation efficiency and consistent drug loading, both of which suggest that the method of preparation was successful in integrating a large amount of curcumin into the carrier system.

The *in vitro* release study demonstrated a two-phase release profile: an early burst followed by gradual release over 48 hours. This pattern is beneficial in clinical settings, as the initial phase can quickly provide therapeutic levels of the drug, while the sustained phase helps maintain those levels over time without requiring frequent dosing.

The MTT assay results clearly showed that curcumin, when delivered through nanoparticles, had a more pronounced cytotoxic effect on MCF-7 breast cancer cells than free curcumin. This increased potency may be attributed to the improved solubility and stability of curcumin in its encapsulated form, along with better uptake by the cells. The cellular uptake study further supported this, as cells treated with nano-curcumin exhibited stronger fluorescence, suggesting higher internalization rates.

These findings are in line with previous research where natural compounds, once incorporated into nanocarriers, showed improved performance against cancer cells. What sets this study apart is the consistent data across all parameters—physicochemical, release kinetics, cytotoxicity, and uptake—which collectively support the conclusion that nanoparticle-mediated delivery enhances the overall therapeutic profile of curcumin.

However, it is important to note that this study was limited to *in vitro* testing. While the results are promising, they represent a preliminary step. Further research involving animal models is essential to evaluate the formulation's behavior in a living system, including aspects such as bio-distribution, clearance, immune response, and actual therapeutic benefit. Future investigations could also explore adding targeting ligands to the nanoparticles to increase specificity and reduce interaction with healthy tissues.

CONCLUSION

This research explored the use of PLGA-based nanoparticles to enhance the delivery and therapeutic impact of curcumin for breast cancer treatment. The formulation achieved consistent particle size, good surface stability, and efficient drug loading, all of which support its suitability for biomedical use.

The main discovery entailed releasing curcumin over a 48-hour span for sustained drug concentration in the body without requiring multiple doses. Tests of cell toxicity demonstrated that breast cancer cells experienced stronger inhibitory effects from nanoparticle-delivered curcumin compared to the free form of the medicine. The formulation of nanoparticles helps curcumin address its intrinsic problems by enabling better uptake by cells along with higher levels of drug activity.

The promising results obtained from this work represent a beginning point toward future development of the process. The validation of the formulation requires additional animal trials for analyzing its *in vivo* behavior and its therapeutic properties alongside safety and distribution aspects. Research should investigate how the implementation of targeting ligands within the system would promote better precision while reducing side effects on healthy cells.

The developed curcumin-loaded PLGA nanoparticles demonstrate potential as an attractive therapeutic option for advanced and non-toxic breast cancer treatment. This combination method between natural compounds and nanomedicine advancements demonstrates potential for better oncological treatment quality and therapeutic methods.

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CONFLICT OF INTEREST: Nil

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