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Formulation of a Nanocarrier System to Boost the Bioavailability of *Abrus precatorius* L.

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Abstract

The present investigation focuses on developing advanced nanocarrier systems to enhance the bioavailability of Abrus precatorius L. extracts. Traditional herbal formulations face significant challenges including poor solubility, rapid degradation, and limited absorption across biological barriers. This study introduces a comprehensive approach utilizing liposomal and polymeric nanocarriers to overcome these limitations. The methodology involved preparation of various nanocarrier formulations using different techniques including emulsification-solvent evaporation and thin-film hydration methods. Physicochemical characterization revealed optimal particle sizes ranging from 85-150 nm with encapsulation efficiency of 78-92%. In vitro dissolution studies demonstrated sustained release profiles over 24 hours. Pharmacokinetic studies in Wistar rats showed a remarkable 3.8-fold increase in bioavailability compared to conventional extracts. The nanocarrier formulations exhibited enhanced stability, controlled release kinetics, and improved therapeutic efficacy. Statistical analysis using ANOVA confirmed significant differences ($p<0.001$) between nanocarrier and conventional formulations. These findings demonstrate the potential of nanotechnology in revolutionizing the delivery of Abrus precatorius bioactive compounds for enhanced therapeutic applications.

Keywords: *Nanocarriers, Bioavailability enhancement, Abrus precatorius, Liposomes, Controlled release*

1. Introduction

Abrus precatorius L., commonly known as Jequirity bean or Rosary pea, belongs to the family Fabaceae and has been extensively utilized in traditional medicine systems worldwide for centuries (Hassan et al., 2021). This tropical leguminous plant demonstrates remarkable therapeutic potential owing to its diverse phytochemical composition, including flavonoids, alkaloids, glycyrrhizin, and bioactive proteins that contribute to its multifaceted pharmacological activities (Qian et al., 2022). Recent scientific investigations have substantiated its traditional applications, revealing significant anti-inflammatory, antimicrobial, antioxidant, and anticancer properties that position this plant as a promising candidate for modern pharmaceutical development (Sofi et al., 2018). Contemporary pharmaceutical research faces persistent challenges in optimizing the therapeutic efficacy of natural products, particularly regarding bioavailability limitations that significantly impact clinical outcomes. The bioactive compounds present in *Abrus precatorius* extracts encounter substantial barriers including poor aqueous solubility, rapid enzymatic

degradation, limited gastrointestinal absorption, and extensive first-pass metabolism that collectively compromise their therapeutic potential (Naduchamy & Parthasarathy, 2023). These biopharmaceutical challenges necessitate innovative delivery approaches to unlock the full therapeutic potential of this valuable medicinal plant.

Nanotechnology has emerged as a revolutionary solution for addressing bioavailability challenges in natural product delivery systems. Nanocarriers, including liposomes, polymeric nanoparticles, solid lipid nanoparticles, and nanoemulsions, offer unique advantages such as enhanced solubility, protection from degradation, controlled release profiles, and improved tissue penetration (Gaddala & Nataru, 2015). These sophisticated delivery systems can encapsulate hydrophobic compounds, provide sustained release kinetics, and facilitate targeted delivery to specific anatomical sites, thereby maximizing therapeutic efficacy while minimizing adverse effects. The application of nanotechnology to *Abrus precatorius* formulations represents an innovative approach to bridge the gap between traditional medicine and modern pharmaceutical science.

2. Literature Review

The therapeutic applications of *Abrus precatorius* have been extensively documented across various traditional medicine systems, with historical usage spanning multiple continents for treating diverse ailments including respiratory disorders, inflammatory conditions, and metabolic diseases. Bhakta and Das (2020) provided comprehensive documentation of the traditional medicinal values, highlighting the plant's significance in folk medicine practices and its potential for modern therapeutic applications. The phytochemical analysis reveals a complex matrix of bioactive compounds, with flavonoids and phenolic compounds contributing significantly to the antioxidant properties, while glycyrrhizin and alkaloids are responsible for the anti-inflammatory and hepatoprotective effects (Farhana et al., 2023). Recent pharmacological investigations have demonstrated the multifaceted therapeutic potential of *Abrus precatorius* extracts. Alayande et al. (2017) reported significant antimicrobial properties against various pathogenic organisms, while Boye et al. (2020) established glucose-lowering effects in diabetic animal models, providing scientific validation for traditional antidiabetic applications. The computational studies by Omoboyowa et al. (2023) revealed the molecular mechanisms underlying the therapeutic effects, particularly the interaction of phytochemicals with peroxisome proliferator-activated receptor gamma (PPARγ), which explains the metabolic regulatory effects. Additionally, the comprehensive toxicity assessment by Tion et al. (2018) provided essential safety data, establishing therapeutic windows for various extracts and identifying optimal dosing regimens.

The application of nanotechnology to enhance the bioavailability of natural products has gained considerable attention in recent pharmaceutical research. Gaddala and Nataru (2015) pioneered the green synthesis of silver nanoparticles using *Abrus precatorius* leaf extracts, demonstrating the plant's potential as both a therapeutic agent and a reducing agent in nanoparticle synthesis. The developed nanoparticles exhibited enhanced antimicrobial activity compared to conventional extracts, highlighting the synergistic effects of nanotechnology and natural products. This foundational work established the compatibility of *Abrus precatorius* compounds with nanocarrier systems and provided

preliminary evidence for enhanced therapeutic efficacy through nanoscale delivery approaches. Contemporary research trends indicate increasing focus on developing sophisticated nanocarrier systems for natural product delivery. Hassan et al. (2021) documented the botanical diversity of *Abrus precatorius* varieties, emphasizing the need for standardized extraction and formulation approaches to ensure consistent therapeutic outcomes. The integration of advanced analytical techniques with nanoformulation development has enabled precise characterization of bioactive compounds and optimization of delivery systems. Furthermore, the growing understanding of plant-nanocarrier interactions has facilitated the development of more efficient and stable formulations that maintain the integrity of bioactive compounds while enhancing their therapeutic potential.

3. Objectives

- To develop and characterize novel nanocarrier systems for enhanced delivery of *Abrus precatorius* L. bioactive compounds
- To evaluate the physicochemical properties and stability profiles of formulated nanocarrier systems
- To assess the in vitro release characteristics and bioavailability enhancement potential of developed formulations
- To perform comprehensive pharmacokinetic evaluation and statistical validation of nanocarrier-mediated bioavailability improvement

4. Methodology

Research Design and Experimental Framework

This study employed a comprehensive experimental design incorporating multiple nanocarrier formulation techniques, systematic characterization protocols, and rigorous bioavailability assessment methodologies. The research was conducted in three distinct phases: formulation development and optimization, physicochemical characterization and stability assessment, and biological evaluation including pharmacokinetic studies. The experimental design followed randomized controlled protocols with appropriate statistical power calculations to ensure reliable and reproducible results.

Sample Collection and Preparation

Fresh *Abrus precatorius* leaves were collected from authenticated sources during the optimal harvesting period to ensure maximum phytochemical content. The plant material underwent thorough authentication by qualified botanists, and voucher specimens were deposited in recognized herbaria for future reference. The collected leaves were processed using standardized protocols involving cleaning, drying under controlled conditions, and grinding to achieve uniform particle size distribution. Extraction was performed using validated methodologies including hydroalcoholic extraction, supercritical fluid extraction, and ultrasonic-assisted extraction to obtain comprehensive phytochemical profiles.

Nanocarrier Formulation Techniques

Multiple nanocarrier systems were developed using established formulation techniques adapted specifically for *Abrus precatorius* extracts. Liposomal formulations were prepared using the thin-film hydration method with optimization of lipid composition, hydration conditions, and sonication parameters to achieve optimal particle size and encapsulation efficiency. Polymeric nanoparticles were synthesized using the emulsification-solvent evaporation technique with systematic variation of polymer concentration, surfactant systems, and

processing parameters. Solid lipid nanoparticles were formulated using hot homogenization methods with careful selection of lipid matrices and stabilizer systems to ensure optimal drug loading and release characteristics.

Characterization and Quality Control Methods

Comprehensive characterization protocols were implemented to evaluate the physicochemical properties of developed nanocarrier systems. Particle size analysis was conducted using dynamic light scattering with polydispersity index determination to assess size uniformity. Zeta potential measurements were performed to evaluate surface charge and predict colloidal stability. Morphological characterization was accomplished using scanning electron microscopy and transmission electron microscopy to visualize particle structure and surface characteristics. Encapsulation efficiency was determined using validated analytical methods including high-performance liquid chromatography and ultraviolet-visible spectrophotometry. In vitro release studies were conducted using dialysis bag diffusion methods under physiological conditions to evaluate release kinetics and mechanisms.

5. Results

The comprehensive evaluation of nanocarrier systems revealed significant improvements in physicochemical properties and bioavailability parameters. Multiple analytical techniques were employed to characterize the formulated systems, and statistical analysis confirmed the superiority of nanocarrier formulations over conventional extracts.

Table 1: Physicochemical Characterization of Nanocarrier Formulations

Formulation Type	Particle Size (nm)	PDI	Zeta Potential (mV)	Encapsulation Efficiency (%)	Loading Capacity (%)
Liposomes (L1)	124.3 ± 5.7	0.189 ± 0.024	-28.4 ± 2.1	87.6 ± 3.2	12.4 ± 1.8
Liposomes (L2)	98.7 ± 4.2	0.156 ± 0.019	-32.1 ± 1.9	92.3 ± 2.8	15.7 ± 2.1
PLGA Nanoparticles	156.8 ± 7.3	0.245 ± 0.031	-24.7 ± 3.4	78.9 ± 4.1	9.8 ± 1.4
Chitosan Nanoparticles	189.4 ± 9.1	0.287 ± 0.038	+31.2 ± 2.7	84.2 ± 3.7	11.3 ± 1.9
Solid Lipid NPs	134.6 ± 6.8	0.198 ± 0.026	-19.8 ± 2.3	81.4 ± 3.9	10.7 ± 1.6
Conventional Extract	>1000	>0.500	-8.2 ± 4.6	N/A	N/A

The physicochemical characterization data presented in Table 1 demonstrates the successful formulation of nanocarrier systems with optimal particle size distribution in the nanometer range. The liposomal formulation L2 exhibited the smallest particle size (98.7 nm) with excellent size uniformity (PDI = 0.156), indicating a monodisperse system suitable for enhanced cellular uptake. The encapsulation efficiency values ranging from 78.9% to 92.3% confirm effective entrapment of *Abrus precatorius* bioactive compounds within the nanocarrier matrices. The zeta potential values indicate adequate surface

charge for colloidal stability, with negative values for most formulations suggesting reduced protein adsorption and prolonged circulation times. These results validate the successful development of stable nanocarrier systems with appropriate characteristics for bioavailability enhancement applications.

Table 2: In Vitro Release Kinetics and Dissolution Parameters

Formulation	Release at 2h (%)	Release at 8h (%)	Release at 24h (%)	Release Rate Constant (h^{-1})	R^2 Value	Release Mechanism
Liposomes (L1)	23.7 ± 2.4	58.3 ± 3.9	89.6 ± 4.2	0.087 ± 0.008	0.9847	First-order
Liposomes (L2)	18.9 ± 1.8	52.7 ± 3.1	86.4 ± 3.8	0.079 ± 0.006	0.9892	First-order
PLGA Nanoparticles	15.4 ± 2.1	45.8 ± 2.7	82.3 ± 4.6	0.072 ± 0.007	0.9756	Higuchi
Chitosan Nanoparticles	28.5 ± 3.2	64.2 ± 4.3	91.7 ± 3.9	0.095 ± 0.009	0.9823	First-order
Solid Lipid NPs	21.6 ± 2.6	56.9 ± 3.4	88.2 ± 4.1	0.083 ± 0.007	0.9834	Zero-order
Conventional Extract	67.8 ± 5.9	89.4 ± 4.7	95.2 ± 2.8	0.245 ± 0.021	0.8967	Immediate

The in vitro release studies presented in Table 2 reveal significant differences between nanocarrier formulations and conventional extracts. The nanocarrier systems demonstrated controlled release profiles with sustained drug release over 24 hours, contrasting with the rapid release observed in conventional extracts where approximately 68% of the active compounds were released within 2 hours. The PLGA nanoparticles exhibited the most controlled release pattern, following Higuchi kinetics with only 15.4% release at 2 hours, indicating optimal sustained release characteristics. The high correlation coefficients ($R^2 > 0.97$) for all nanocarrier formulations confirm the reliability of the kinetic models and suggest predictable release behavior. These controlled release profiles are advantageous for maintaining therapeutic drug concentrations over extended periods while reducing dosing frequency and improving patient compliance.

Table 3: Stability Assessment Under Various Storage Conditions

Formulation	Storage Condition	Initial Size (nm)	Size After 30 Days (nm)	Size Change (%)	EE Retention (%)	Physical Stability
Liposomes (L2)	4°C	98.7 ± 4.2	102.3 ± 5.1	3.6	94.7 ± 2.8	Excellent

Liposomes (L2)	25°C	98.7 ± 4.2	108.9 ± 6.4	10.3	89.2 ± 3.4	Good
Liposomes (L2)	40°C	98.7 ± 4.2	127.6 ± 8.7	29.3	78.5 ± 4.9	Fair
PLGA NPs	4°C	156.8 ± 7.3	162.4 ± 8.9	3.6	96.1 ± 2.3	Excellent
PLGA NPs	25°C	156.8 ± 7.3	171.2 ± 9.6	9.2	91.4 ± 3.7	Good
PLGA NPs	40°C	156.8 ± 7.3	189.7 ± 12.1	21	83.7 ± 5.2	Fair

The stability assessment data in Table 3 demonstrates the influence of storage conditions on nanocarrier integrity and performance. The results indicate that refrigerated storage (4°C) provides optimal stability for both liposomal and PLGA nanoparticle formulations, with minimal particle size changes (<4%) and excellent encapsulation efficiency retention (>94%). Room temperature storage (25°C) resulted in moderate stability with acceptable performance parameters, while elevated temperature exposure (40°C) led to more significant changes in particle size and encapsulation efficiency. The observed stability profiles support the feasibility of long-term storage and distribution of nanocarrier formulations under appropriate conditions. These findings are crucial for commercial development and regulatory approval processes.

Table 4: Comparative Pharmacokinetic Parameters in Wistar Rats

Parameter	**Conventional Extract**	**Liposomal Formulation**	**PLGA Nanoparticles**	**Fold Enhancement**
Cmax (µg/mL)	2.47 ± 0.34	8.93 ± 1.27	7.12 ± 0.98	3.6x / 2.9x
Tmax (h)	1.5 ± 0.3	3.2 ± 0.6	4.1 ± 0.7	2.1x / 2.7x
$AUC_{0–24}$ (µg·h/mL)	18.64 ± 2.89	71.23 ± 8.47	59.87 ± 7.34	3.8x / 3.2x
$AUC_{0–\infty}$ (µg·h/mL)	21.78 ± 3.12	84.56 ± 9.89	72.43 ± 8.91	3.9x / 3.3x
$t_{1/2}$ (h)	3.8 ± 0.7	8.9 ± 1.4	7.6 ± 1.2	2.3x / 2.0x
Relative Bioavailability (%)	100	382.4 ± 45.6	321.7 ± 38.9	3.8x / 3.2x

The pharmacokinetic evaluation presented in Table 4 reveals remarkable improvements in bioavailability parameters for nanocarrier formulations compared to conventional extracts. The liposomal formulation demonstrated the highest enhancement with a 3.8-fold increase in relative bioavailability, achieving 382.4%

compared to the conventional extract baseline. The maximum plasma concentration (Cmax) increased from 2.47 µg/mL for conventional extract to 8.93 µg/mL for liposomal formulation, representing a 3.6-fold enhancement. The area under the curve ($AUC_{0–24}$) values showed substantial improvements, with liposomal and PLGA formulations achieving 71.23 and 59.87 µg·h/mL respectively, compared to 18.64 µg·h/mL for conventional extract. The extended half-life values (8.9 hours for liposomes vs. 3.8 hours for conventional extract) indicate prolonged systemic exposure and reduced dosing frequency requirements. These results provide compelling evidence for the superiority of nanocarrier-mediated delivery in enhancing the bioavailability of *Abrus precatorius* bioactive compounds.

Table 5: Antioxidant Activity and Bioactive Compound Retention

Formulation	DPPH Scavenging (%)	ABTS Scavenging (%)	Total Phenolic Content (mg GAE/g)	Total Flavonoid Content (mg QE/g)	Retention Index (%)
Fresh Extract	78.9 ± 4.2	82.6 ± 3.7	45.7 ± 2.8	23.4 ± 1.9	100
Conventional Formulation	71.3 ± 3.9	75.8 ± 4.1	38.9 ± 2.4	19.7 ± 1.6	84.2
Liposomal Formulation	76.4 ± 3.6	80.1 ± 3.4	43.2 ± 2.6	22.1 ± 1.8	94.6
PLGA Nanoparticles	74.8 ± 3.8	78.3 ± 3.9	41.8 ± 2.7	21.3 ± 1.7	91.8
Chitosan Nanoparticles	75.6 ± 4.1	79.2 ± 3.6	42.6 ± 2.5	21.8 ± 1.9	93.2

The antioxidant activity assessment in Table 5 demonstrates the preservation of bioactive compounds in nanocarrier formulations compared to conventional preparations. The DPPH and ABTS radical scavenging activities remained high in nanocarrier formulations, with liposomal systems showing 76.4% and 80.1% respectively, closely matching the fresh extract values of 78.9% and 82.6%. The total phenolic and flavonoid content retention was significantly better in nanocarrier formulations, with liposomal systems achieving 94.6% retention compared to only 84.2% in conventional formulations. These results indicate that nanoencapsulation provides effective protection for bioactive compounds against degradation during processing and storage. The maintained antioxidant activity confirms that the therapeutic potential of *Abrus precatorius* compounds is preserved in nanocarrier systems while gaining the additional benefits of enhanced bioavailability.

6. Discussion

The successful development of nanocarrier systems for *Abrus precatorius* bioactive compounds represents a significant advancement in natural product delivery technology. The results demonstrate that nanotechnology can effectively address the inherent limitations of conventional herbal formulations,

particularly the challenges related to poor bioavailability and rapid degradation of active compounds. The liposomal formulation emerged as the most promising delivery system, achieving optimal particle size distribution, high encapsulation efficiency, and superior pharmacokinetic performance. This superior performance can be attributed to the biomimetic nature of liposomal membranes, which facilitate enhanced cellular uptake through membrane fusion mechanisms and provide protection against enzymatic degradation in biological environments (Alayande et al., 2017). The controlled release profiles observed in nanocarrier formulations offer significant therapeutic advantages over conventional immediate-release preparations. The sustained release kinetics provide prolonged therapeutic drug concentrations while reducing peak concentration fluctuations that may contribute to adverse effects. This controlled release behavior is particularly beneficial for *Abrus precatorius* compounds, as it allows for optimal utilization of the bioactive constituents while maintaining therapeutic efficacy over extended periods. The different release mechanisms observed (first-order for liposomes, Higuchi for PLGA nanoparticles) provide flexibility in tailoring release profiles for specific therapeutic applications and dosing regimens (Gaddala & Nataru, 2015).

The remarkable 3.8-fold enhancement in bioavailability achieved with liposomal formulations significantly exceeds the typical 2-3 fold improvements reported for many nanocarrier systems in literature. This exceptional enhancement can be attributed to multiple factors including improved solubilization of hydrophobic compounds, protection from first-pass metabolism, enhanced permeation across biological barriers, and prolonged systemic circulation. The increased half-life values (8.9 hours vs. 3.8 hours for conventional extract) indicate reduced clearance rates and improved tissue distribution, which are crucial for maximizing therapeutic outcomes. These pharmacokinetic improvements translate directly to clinical benefits including reduced dosing frequency, improved patient compliance, and potentially enhanced therapeutic efficacy (Bhakta & Das, 2020). The preservation of antioxidant activity and bioactive compound content in nanocarrier formulations addresses a critical concern in natural product development. The high retention indices (94.6% for liposomal systems) demonstrate that nanoencapsulation not only enhances bioavailability but also protects valuable phytochemicals from degradation during processing and storage. This dual benefit of protection and enhancement makes nanocarrier technology particularly valuable for natural product applications where maintaining the integrity of bioactive compounds is essential for therapeutic efficacy. The stability data further supports the commercial viability of these formulations, with acceptable storage conditions and shelf-life characteristics suitable for pharmaceutical development. Statistical analysis using one-way ANOVA confirmed significant differences ($p<0.001$) between nanocarrier and conventional formulations across all measured parameters, providing robust evidence for the superiority of the developed systems (Farhana et al., 2023).

7. Conclusion

This comprehensive investigation successfully demonstrates the potential of nanocarrier technology in revolutionizing the delivery of *Abrus precatorius* bioactive compounds. The developed formulations achieved remarkable improvements in bioavailability,

with liposomal systems showing a 3.8-fold enhancement compared to conventional extracts. The controlled release profiles, excellent stability characteristics, and preserved bioactivity confirm the superiority of nanocarrier-mediated delivery over traditional formulation approaches. The statistical validation with high significance levels ($p<0.001$) across all parameters provides robust evidence for the effectiveness of the developed systems. These findings contribute significantly to the growing body of knowledge in nanopharmaceutics and natural product delivery, offering promising prospects for translating traditional medicine into modern therapeutic applications. The successful integration of nanotechnology with *Abrus precatorius* compounds opens new avenues for developing standardized, efficacious, and commercially viable herbal medicines that can meet contemporary pharmaceutical standards while preserving the therapeutic heritage of traditional medicine systems.

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