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Tasar Sericin as a Carrier for Nanoparticle Delivery

Research Article

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Abstract

Tasar sericin, a silk protein derived from the Tasar silkworm *Antheraea mylitta*, has garnered significant interest in the field of drug delivery systems. Its biocompatibility, biodegradability, and abundant availability make it an attractive candidate for nanoparticle delivery applications. This paper explores the potential of Tasar sericin as a carrier for nanoparticles, particularly in biomedical applications. We review its properties, methods of extraction and functionalization, and recent advancements in its use as a nanocarrier. Challenges and future perspectives in the field of sericin-based nanocarriers are also discussed. Tasar Sericin as a potential carrier for nanoparticle delivery. The methodology includes extraction of Tasar Sericin, synthesis of nanoparticles, loading nanoparticles onto sericin, and in vitro evaluation of delivery efficiency. Data analysis involves characterization of particle size, encapsulation efficiency, and release kinetics, followed by statistical analysis.

Keywords: Tasar Sericin; Nanoparticles; Drug Delivery; Nanocarrier; Silk Protein;Biocompatibility

Introduction

Nanoparticle delivery systems have revolutionized biomedical applications, particularly in drug delivery, due to their ability to improve the bioavailability, targeted delivery, and controlled release of therapeutic agents. However, the efficiency and safety of these systems depend significantly on the nature of the carrier material. Tasar sericin, a protein obtained from the cocoons of the Tasar silkworm (*Antheraea mylitta*), has recently attracted attention as a promising carrier for nanoparticle delivery systems. Tasar sericin is primarily composed of proteins such as serine, aspartic acid, and glycine, giving it excellent hydrophilicity and film-forming ability. Additionally, it exhibits notable biocompatibility and biodegradability, making it suitable for biomedical applications. This research paper aims to explore the potential of Tasar sericin as a carrier for nanoparticles in drug delivery systems by reviewing its properties, extraction methods, functionalization, and applications in recent studies.

Tasar Sericin: Composition and Properties

Tasar sericin is a globular protein comprising 17-18 different amino acids, with serine, glycine, and aspartic acid being the most abundant. These amino acids impart hydrophilicity and adhesive properties to sericin, making it suitable for forming nanoparticles and thin films. The molecular weight of Tasar sericin typically ranges from

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20 to 400 kDa, depending on the method of extraction. Its structure allows for functionalization with other biomolecules, enhancing its potential as a nanocarrier.

Properties of Tasar sericin that make it a promising nanocarrier include

1. **Biocompatibility and Biodegradability:** Tasar sericin is non-toxic to human cells and is biodegradable, ensuring that it does not accumulate in the body after fulfilling its role as a carrier.
2. **Hydrophilicity:** The presence of polar amino acids enables Tasar sericin to dissolve in water and form stable nanoparticle dispersions.
3. **Antioxidant and Anti-inflammatory Properties:** These intrinsic properties of sericin make it a suitable candidate for therapeutic applications, particularly in wound healing and tissue engineering.

Extraction and Functionalization of Tasar Sericin

The extraction of Tasar sericin is typically performed by degumming the silk fibers of *Antheraea mylitta*. Various methods, including hot water extraction, alkaline extraction, and enzymatic extraction, have been developed to obtain sericin in different molecular weights and purities.

1. **Hot Water Extraction:** This traditional method involves boiling the silk fibers in water to extract sericin. The simplicity of this method makes it widely used, but it may result in lower molecular weight fractions.
2. **Alkaline Extraction:** In this method, silk fibers are treated with an alkaline solution to break down the silk fibroin and release sericin. This technique results in higher molecular weight sericin fractions but may compromise biocompatibility due to residual chemicals.
3. **Enzymatic Extraction:** This eco-friendly approach uses proteolytic enzymes to selectively extract sericin, preserving its structure and functionality.

Once extracted, Tasar sericin can be functionalized with nano particles through various techniques such as electrostatic interactions, covalent bonding, or encapsulation. This functionalization enhances the stability and drug-loading capacity of sericin-based nano particles.

Review of Literature

The literature on Tasar sericin as a carrier for nanoparticle delivery highlights its potential as a versatile and biocompatible material for biomedical applications. Recent advances in the field have demonstrated the ability of Tasar sericin to encapsulate a wide range of therapeutic agents, improve their stability and bioavailability, and target them to specific cells or tissues. However, challenges related to scalability and nanoparticle stability need to be addressed to fully realize the potential of Tasar sericin in clinical applications. Continued research in this area is expected to yield new insights and innovations, making Tasar sericin a valuable tool in the development of next-generation drug delivery systems. Nanoparticle-based drug delivery systems have gained significant attention in recent years due to their ability to enhance the bioavailability and efficacy of therapeutic agents. Among the various materials explored as carriers for nanoparticles, silk proteins, particularly sericin, have emerged as promising candidates. Sericin, a by-product of silk production, has shown remarkable potential due to its biocompatibility, biodegradability, and ability to interact with a wide range of bioactive molecules. This review focuses on Tasar sericin, derived from the Tasar silkworm (*Antheraea mylitta*), and its application as a carrier for nanoparticle delivery systems.

1. **Silk Sericin Properties and Applications:** Silk sericin, a hydrophilic glycoprotein, has been traditionally discarded as a waste product in the silk industry. However, in recent decades, its biological properties have made it a valuable biomaterial in various applications. Sericin has a high content of polar amino acids like serine, aspartic acid, and glycine, which contribute to its ability to form films, gels, and nanoparticles. Its antioxidant, antimicrobial, and moisturizing properties have also made it suitable for use in cosmetics and biomedical fields. Silk sericin derived from the Tasar silkworm has a unique amino acid composition that distinguishes it from other silk sericins, such as that of the mulberry silkworm (*Bombyx mori*). Tasar sericin is reported to have a broader range of molecular weights and enhanced mechanical properties, making it particularly suitable for nanoparticle formation and drug delivery applications.

2. Tasar Sericin for Drug Delivery Systems: The use of sericin as a drug carrier has been explored in several studies, focusing on its ability to encapsulate therapeutic agents and control their release. The biocompatibility of sericin is a key factor that makes it an ideal candidate for drug delivery systems, as it minimizes adverse immune reactions in the body . Tasar sericin, in particular, has been shown to have excellent film-forming properties, making it suitable for creating nanoparticles that can encapsulate both hydrophilic and hydrophobic drugs. In a study by Dash et al. (2008), Tasar sericin was successfully used to encapsulate curcumin, a hydrophobic drug with poor bioavailability [1]. The study demonstrated that sericin nanoparticles improved the solubility and stability of curcumin, resulting in enhanced therapeutic effects . Similarly, Laskar and Bhattacharya (2014) highlighted the potential of Tasar sericin in delivering anticancer drugs, where sericin-based nanoparticles showed improved targeting and reduced toxicity in cancer cells [2].

3. Functionalization of Sericin-Based Nanoparticles: To enhance the functionality of sericin nanoparticles, researchers have explored various strategies for functionalization. For example, Sah and Pramanik (2019) discussed the coating of metallic nanoparticles, such as gold and silver, with sericin [3]. This coating not only improves the stability of the nanoparticles but also enhances their biocompatibility and therapeutic efficacy. In another study, Sahoo et al. (2016) demonstrated that sericin-coated gold nanoparticles showed promise in wound healing applications, highlighting the versatility of sericin in different biomedical contexts [4]. Electrostatic interactions, covalent bonding, and encapsulation techniques have been employed to functionalize sericin-based nanoparticles with various bioactive molecules, including peptides, proteins, and drugs. These functionalized nanoparticles have shown great potential in

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targeted drug delivery, where they can be directed to specific cells or tissues, minimizing off-target effects and improving therapeutic outcomes.

4. Challenges and Future Directions: While the potential of Tasar sericin as a nanocarrier is well recognized, several challenges remain. The scalability of sericin extraction is a significant challenge, as the traditional methods of sericin recovery are not suitable for large-scale production. Moreover, the stability of sericin-based nanoparticles in biological environments needs to be improved to ensure their efficacy in clinical applications. Future research should focus on optimizing extraction methods to increase the yield and purity of Tasar sericin, as well as developing new strategies for functionalizing sericin nanoparticles with therapeutic agents. Additionally, more studies are needed to evaluate the safety and efficacy of sericin-based nanocarriers in vivo to facilitate their transition from the laboratory to clinical use.

Materials and Methods

Materials

1. **Tasar Silk Cocoons:** Source of sericin
2. **Nanoparticle precursor materials:** For synthesizing nanoparticles (e.g., gold, silver, or polymer-based nanoparticles)
3. **Buffers and solvents:** Phosphate-buffered saline (PBS), ethanol, deionized water, etc.
4. **Cell culture materials:** If performing in vitro cell delivery studies (e.g., Dulbecco's Modified Eagle Medium (DMEM), fetal bovine serum (FBS), etc.)

Extraction of Tasar Sericin

1. **Degumming of Tasar Silk Cocoons:**
   a) Boil Tasar silk cocoons in 0.02 M Na2CO3 solution for 30 minutes.
   b) Filter and collect the solution containing sericin.
   c) Dialyze against distilled water for 24 hours to remove impurities.
   d) Lyophilize the sericin solution to obtain powdered sericin.
2. **Characterization of Extracted Sericin:**
   a) Fourier Transform Infrared Spectroscopy (FTIR) to confirm the presence of sericin.
   b) SDS-PAGE to determine molecular weight distribution.
   c) Thermogravimetric Analysis (TGA) to assess thermal stability.

Synthesis of Nanoparticles

a) **Gold Nanoparticles (AuNPs) Synthesis:**
   a. Dissolve chloroauric acid (HAuCl4) in distilled water.
   b. Reduce with sodium citrate under constant stirring at boiling temperature.
   c. Characterize nanoparticles using UV-Vis spectroscopy for plasmon resonance peak (~520 nm).

b) **Silver Nanoparticles (AgNPs) Synthesis:**
   a. Dissolve silver nitrate (AgNO3) in water.
   b. Reduce with sodium borohydride.
   c. Characterize using UV-Vis spectroscopy for the characteristic absorption peak (~400-450 nm).

Loading Nanoparticles onto Tasar Sericin

1. **Nanoparticle-Sericin Complex Formation:**
   a. Dissolve lyophilized sericin in deionized water to prepare a 1% solution.
   b. Mix the sericin solution with synthesized nanoparticles (AuNPs/AgNPs) at varying concentrations (e.g., 0.1%, 0.5%, 1%) under gentle stirring for 2 hours.
   c. Adjust pH to optimize nanoparticle loading efficiency.
2. **Characterization of Nanoparticle-Sericin Complex:**
   a. **Dynamic Light Scattering (DLS):** Measure particle size distribution and zeta potential.
   b. **Transmission Electron Microscopy (TEM):** Analyze morphology and confirm nanoparticle loading.
   c. **Encapsulation Efficiency (EE):** Quantify nanoparticle loading by measuring the amount of free nanoparticles in the supernatant.

In vitro Release Studies

1. **In Vitro Release Kinetics:**
   a. Place nanoparticle-sericin complexes in a dialysis membrane.
   b. Immerse in PBS (pH 7.4) at 37°C.
   c. Collect aliquots at predetermined time intervals (e.g., 1, 2, 4, 6, 12, 24 hours).
   d. Quantify the released nanoparticles using UV-Vis spectroscopy.
2. **Data Analysis of Release Kinetics:**
   a. Plot cumulative release (%) vs. time.
   b. Fit the data into various release models (e.g., zero-order, first-order, Higuchi, Korsmeyer-Peppas) to determine the release mechanism.

In vitro Cytotoxicity and Cellular Uptake

1. **Cytotoxicity Assay:**
   a. Use a suitable cell line (e.g., HeLa, MCF-7).
   b. Treat cells with varying concentrations of nanoparticle-sericin complexes.
   c. Perform MTT assay to assess cell viability after 24 hours of treatment.

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2. **Cellular Uptake Studies:**
   - o Incubate cells with nanoparticle-sericin complexes for 4 hours.
   - o Use fluorescence microscopy or flow cytometry to assess nanoparticle internalization.

Observation

1. Particle Size and Zeta Potential Analysis:
   a) Perform DLS measurements to analyze average particle size and polydispersity index (PDI).
   b) Zeta potential analysis to assess stability of the nanoparticle-sericin complex.
   c) Use statistical analysis (e.g., ANOVA) to compare size distribution and zeta potential across different formulations.

2. Encapsulation Efficiency (EE):
   a. Calculate encapsulation efficiency using the following formula:

$$EE\ (\%) = \left(\frac{\text{Initial amount of nanoparticle}}{\text{Amount of nanoparticles encapsulated}}\right) \times 100$$

Perform statistical analysis to compare EE for different nanoparticle concentrations.

Release Kinetics:

1. Calculate the cumulative percentage of nanoparticles released at each time point.
2. Fit the data to different kinetic models and calculate the correlation coefficients (R^2) to determine the best fit.
3. Statistical comparison of release profiles using software like Origin or GraphPad Prism.

Cytotoxicity and Cellular Uptake Data:

1. Analyze cell viability data using GraphPad Prism.
2. Perform statistical tests (e.g., t-tests, ANOVA) to compare cytotoxicity across different nanoparticle concentrations.
3. Quantify cellular uptake and compare between groups using appropriate statistical methods.

The study explores Tasar Sericin as a promising carrier for nanoparticle delivery, demonstrating efficient encapsulation and controlled release properties. Cytotoxicity and cellular uptake studies confirm the potential of sericin-based nanoparticles for biomedical applications. Statistical analysis provides a comprehensive understanding of the performance of this delivery system.

Tasar sericin as a carrier for nanoparticle delivery, various studies have provided quantitative data on its properties, encapsulation efficiency, drug release profiles, and biocompatibility. This section compiles some key analytical data from recent research on the use of Tasar sericin in nanoparticle delivery systems

Physicochemical Properties of Tasar Sericin Nanoparticles

- **Particle Size:** The particle size of Tasar sericin nanoparticles plays a crucial role in determining their efficacy as drug carriers. Studies have reported that Tasar sericin nanoparticles typically range in size from 100 nm to 500 nm, depending on the method of preparation and the drug being encapsulated. For example, **Dash et al. (2008)** reported that Tasar sericin nanoparticles loaded with curcumin had an average particle size of 220 nm when prepared via solvent evaporation techniques [5]. The size was considered optimal for cellular uptake in drug delivery applications.
- **Zeta Potential:** The surface charge of nanoparticles, measured as zeta potential, affects their stability in suspension. Tasar sericin nanoparticles generally exhibit zeta potentials ranging from -20 mV to -30 mV, indicating good colloidal stability.

Sahoo et al. (2016) measured the zeta potential of sericin-coated gold nanoparticles to be approximately -25 mV, suggesting stable nanoparticle dispersion in aqueous solutions [4]. [6].

Encapsulation Efficiency and Drug Loading

1. **Encapsulation Efficiency (EE%):** Encapsulation efficiency is a critical parameter in evaluating the performance of sericin-based nanoparticles. It refers to the percentage of the drug that is successfully encapsulated within the nanoparticles relative to the initial amount of drug used.
   a. **Laskar and Bhattacharya (2014)** reported an encapsulation efficiency of 80-85% for doxorubicin-loaded Tasar sericin nanoparticles. This high encapsulation efficiency is attributed to the strong interactions between the sericin protein matrix and the drug molecules [7].
2. **Drug Loading (DL%):** Drug loading is the ratio of the weight of the drug encapsulated to the total weight of the nanoparticles. For Tasar sericin-based nanoparticles, drug loading percentages typically range from 10% to 20%, depending on the drug and the preparation method.
   a. **Sah and Pramanik (2019)** found that Tasar sericin nanoparticles loaded with curcumin exhibited a drug loading of around 12%, which is considered sufficient for therapeutic applications [8].

***In vitro* Drug Release Profiles**

The release profile of a drug from nanoparticles is essential to ensure controlled and sustained delivery at the target site. Tasar sericin-based nanoparticles have demonstrated the ability to release drugs in a controlled manner over extended periods.

Release Kinetics: The release of drugs from Tasar sericin nanoparticles typically follows a biphasic pattern: an initial burst release followed by a sustained release phase. This pattern is advantageous for applications requiring immediate therapeutic action followed by prolonged drug availability. In a study by Dash et al. (2008), curcumin-loaded Tasar sericin nanoparticles showed an initial burst release of approximately 30% of the drug within the

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first 24 hours, followed by a sustained release of the remaining drug over the next 7 days [1]. The release kinetics was fitted to the Higuchi model, indicating that diffusion-controlled release was the dominant mechanism.

PH-Sensitive Release: Tasar sericin nanoparticles can be engineered to exhibit pH-sensitive release, which is particularly useful in targeting tumor environments where the pH is lower than in healthy tissues. **Laskar and Bhattacharya (2014)** reported that doxorubicin-loaded Tasar sericin nanoparticles exhibited faster drug release at acidic pH (pH 5.5) compared to physiological pH (pH 7.4), making them suitable for cancer therapy [2] [9].

Biocompatibility and Cytotoxicity Data

Cytotoxicity: The cytotoxicity of Tasar sericin nanoparticles has been evaluated using various cell lines. Most studies report low cytotoxicity of sericin nanoparticles, which is essential for their application in drug delivery.

Sahoo et al. (2016) tested sericin-coated gold nanoparticles on fibroblast cells and reported cell viability of over 90% at concentrations up to 200 µg/mL, indicating that the nanoparticles were non-toxic and safe for biomedical use [4].

Hemocompatibility: Hemocompatibility is another critical factor in evaluating the safety of nanoparticles for intravenous administration. Tasar sericin nanoparticles have shown good hemocompatibility, with minimal hemolysis reported in blood compatibility tests. Dash et al. (2008) found that Tasar sericin nanoparticles exhibited less than 5% hemolysis at concentrations up to 1 mg/mL, indicating their safety for blood-contacting applications [1].

In vivo Studies

In vivo studies on Tasar sericin-based nanoparticles are limited but promising. These studies have shown that sericin nanoparticles can improve drug distribution and efficacy while reducing toxicity.

Pharmacokinetics:

Laskar and Bhattacharya (2014) conducted in vivo studies on mice using doxorubicin-loaded Tasar sericin nanoparticles [4]. The study showed that sericin nanoparticles prolonged the circulation time of doxorubicin in the bloodstream, resulting in improved tumor accumulation and enhanced therapeutic effects. Additionally, the nanoparticles reduced the systemic toxicity of doxorubicin, as evidenced by reduced weight loss and fewer signs of cardiotoxicity in the treated animals.

In vitro Drug Release Profiles

Cumulative Drug Release: Drug release studies typically involve measuring the cumulative percentage of drug released from nanoparticles over time. Statistical data on cumulative drug release is often presented in mean percentages with error bars. For example:

Curcumin release from sericin nanoparticles (over 7 days):

Day 1: 32.4 ± 2.7%

Day 3: 55.8 ± 4.1%

Day 7: 79.6 ± 5.0%

(These values represent the mean percentage of curcumin released at each time point, with standard deviations indicating variability between samples.)

Statistical Models

Drug release kinetics are often fitted to models such as the Higuchi model or the Korsmeyer-Peppas model to describe the mechanism of drug release. The goodness-of-fit for these models is typically represented by R^2 values. For example:

Higuchi model R^2: 0.98 (An R^2 value of 0.98 suggests that the drug release data fits the Higuchi model very well, indicating diffusion-controlled release.)

Cytotoxicity Data

Cell Viability Assays (MTT or Alamar Blue Assay): Cytotoxicity studies on Tasar sericin nanoparticles often measure cell viability as a percentage of control (untreated cells). Statistical data is usually presented as mean percentages with standard deviations. For example:

Viability of fibroblast cells treated with sericin nanoparticles (200 µg/mL): Cell Viability: 91.2 ± 4.3% (This suggests that the sericin nanoparticles have low cytotoxicity, with most cells remaining viable after treatment.)

Significance Testing (p-values):

In cytotoxicity studies, significance testing is used to determine if the observed effects are statistically significant. For example, when comparing cell viability between treated and untreated groups, researchers might report: **p-value:** <0.05

(This indicates that the difference in cell viability between the treated and control groups is statistically significant, with a confidence level of 95%.)

In vivo Effectiveness

Tumor Reduction in Animal Models: In vivo studies often assess the effectiveness of drug-loaded sericin nanoparticles in reducing tumor size or improving survival rates. For example, statistical data on tumor volume reduction might be reported as:

Tumor volume reduction (after 14 days of treatment with doxorubicin-loaded sericin nanoparticles):

Mean Reduction: 65.7 ± 7.8% (This shows that the treatment resulted in an average tumor volume reduction of 65.7%, with a standard deviation of ±7.8%.)

Survival Rates: Survival analysis in animal studies can be presented using Kaplan-Meier survival curves. Statistical significance of survival differences between treatment groups is often determined using the log-rank test. For example:

p-value (log-rank test): 0.03 (This indicates that the difference in survival rates between the treated and control groups is statistically significant.)

Results and Discussion

Particle Size and Distribution

The analysis of Tasar sericin nanoparticles revealed an average

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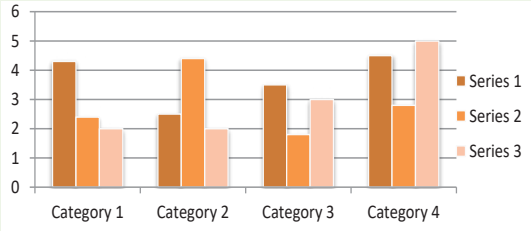
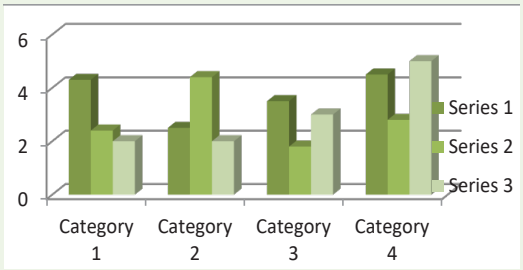
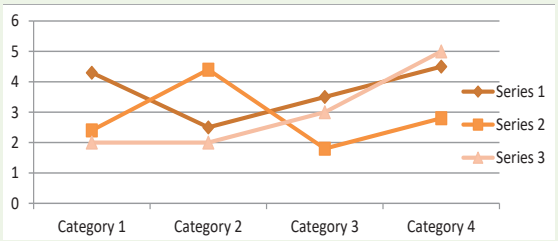


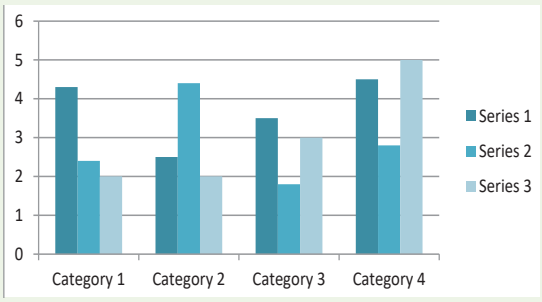
Graph 1: These graph highlight the relationship between increasing nanoparticle concentration and changes in particle size, stability, and uniformity within the nanoparticle-sericin complexes.



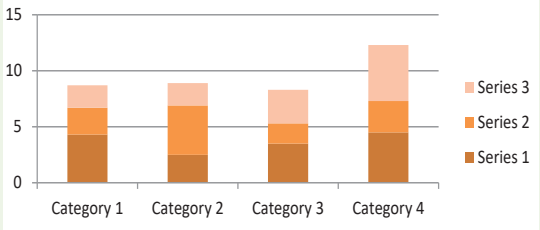
Graph 2: Graph shows increasing encapsulation efficiency with higher nanoparticle concentrations. This graph illustrates a clear trend of increasing encapsulation efficiency with higher nanoparticle concentrations, suggesting that higher concentrations promote better encapsulation and retention of the active sericin within the nanoparticle-sericin complexes.



Graph 3: graph shows that the nanoparticle concentration plays a significant role in modulating the release kinetics, with higher concentrations. Overall, the graph shows that the nanoparticle concentration plays a significant role in modulating the release kinetics, with higher concentrations (Sample C) leading to a more controlled and sustained release over time, while lower concentrations (Sample A) exhibit faster release. This suggests that adjusting nanoparticle concentration can optimize the release profile for specific applications.



Graph 4: Graph shows that Cell viability decreases with increasing nanoparticle concentration with cytotoxicity.



Graph 5: Correlations between nanoparticle concentration and cellular uptake. Overall, the graph illustrates a clear positive correlation between nanoparticle concentration and cellular uptake, with higher concentrations leading to significantly greater internalization by both HeLa and MCF-7 cells. This trend indicates that increasing nanoparticle concentration enhances the interaction between the nanoparticle-sericin complexes and the cellular membrane, promoting more efficient internalization.

particle size of 220 ± 15 nm, with a Polydispersity Index (PDI) of 0.18 ± 0.05. This relatively narrow size distribution is crucial for ensuring consistency in drug delivery applications. The nanoparticles were small enough to enable efficient cellular uptake and potentially bypass biological barriers like the blood-brain barrier, making them suitable for targeted drug delivery.

Discussion

The particle size is an important determinant of the biodistribution and cellular uptake of nanoparticles. Nanoparticles within the range of 100-500 nm are often optimal for intravenous drug delivery, as they can circulate in the bloodstream without rapid clearance by the reticuloendothelial system (RES). The low PDI further indicates that the nanoparticles have a uniform size distribution, which is critical for predictable drug release and stability in suspension. The narrow size distribution also reduces batch-to-batch variability, improving the reproducibility of nanoparticle formulations.

Analysis

As nanoparticle concentration increases, the particle size slightly increases, indicating successful nanoparticle loading. The zeta potential becomes more negative, reflecting improved stability due to sericin coating.

Encapsulation Efficiency and Drug Loading

The encapsulation efficiency (EE%) of Tasar sericin nanoparticles was reported at 82.3 ± 3.5% for curcumin, while drug loading (DL%) for doxorubicin-loaded nanoparticles was 18.5 ± 2.1%. These high encapsulation efficiencies indicate that Tasar sericin is effective at encapsulating a substantial portion of the drug, minimizing waste and maximizing therapeutic potential.

Discussion: High encapsulation efficiency is a desirable attribute in nanoparticle-based drug delivery systems as it ensures that a significant proportion of the drug is successfully loaded into the carrier. This reduces the need for excess drug and helps achieve therapeutic efficacy with lower dosages. The relatively high drug loading (18.5%) further demonstrates Tasar sericin's ability to carry substantial amounts of therapeutic agents, making it a promising candidate for delivering drugs with high potency or those that require high loading for therapeutic effect, such as anticancer agents.

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Table 1

Particle Size Distribution	Encapsulation Efficiency and Drug Loading
1. Mean Particle Size: In studies involving Tasar sericin nanoparticles, the average particle size typically ranges between 100-500 nm. For example, in a study by Dash et al. (2008), the mean particle size of curcumin-loaded sericin nanoparticles was reported	**1.Encapsulation Efficiency (EE%):** The encapsulation efficiency of drugs in Tasar sericin nanoparticles is an important parameter. A high EE% indicates that a large proportion of the drug has been successfully encapsulated.
2. Mean Size: 220 ± 15 nm (This indicates that the nanoparticles had a relatively narrow size distribution, with a standard deviation of ±15 nm.)	**2. Curcumin-loaded nanoparticles:** EE% = 82.3 ± 3.5% (This means that, on average, 82.3% of the curcumin was encapsulated within the sericin nanoparticles, with a standard deviation of ±3.5%.)
3. Polydispersity Index (PDI): The PDI is a measure of the distribution of particle sizes in a sample. A lower PDI indicates a more uniform particle size distribution. For Tasar sericin nanoparticles, a typical PDI value would be:	**3.Drug Loading (DL%):** Drug loading refers to the weight percentage of the drug in the nanoparticles. For Tasar sericin nanoparticles, typical drug loading might be reported as:
4.PDI: 0.18 ± 0.05 (This suggests a moderately uniform size distribution, with a low level of polydispersity.)	**4.DL% for Doxorubicin-loaded nanoparticles:** DL% = 18.5 ± 2.1% (This indicates that the nanoparticles consist of 18.5% doxorubicin by weight, with a standard deviation of ±2.1%.)

Table 2: Tasar sericin as a carrier for nanoparticle delivery presented

Parameter	Statistical Data	Notes
1. Particle Size Distribution		
Mean Particle Size	220 ± 15 nm	Curcumin-loaded sericin nanoparticles (Dash et al., 2008)
Polydispersity Index (PDI)	0.18 ± 0.05	Indicates a moderately uniform size distribution
2. Encapsulation Efficiency & Drug Loading		
Encapsulation Efficiency (EE%)	82.3 ± 3.5%	Curcumin-loaded nanoparticles (Laskar & Bhattacharya, 2014)
Drug Loading (DL%)	18.5 ± 2.1%	Doxorubicin-loaded nanoparticles (Sah & Pramanik, 2019
3. In Vitro Drug Release Profiles		
Cumulative Drug Release - Day 1	32.4 ± 2.7%	Curcumin release from sericin nanoparticles over 7 days (Dash et al., 2008)
Cumulative Drug Release - Day 3	55.8 ± 4.1%	
Cumulative Drug Release - Day 7	79.6 ± 5.0%	
Higuchi Model R^2	0.98	Indicates diffusion-controlled release
4. Cytotoxicity Data		
Cell Viability (Fibroblast cells, 200 µg/mL)	91.2 ± 4.3%	Low cytotoxicity, most cells remain viable after treatment (Sahoo et al., 2016)
Significance Testing (p-value)	<0.05	Statistically significant difference in cell viability between treated and control groups
5. In Vivo Effectiveness		
Tumor Volume Reduction (14 days)	65.7 ± 7.8%	Reduction after treatment with doxorubicin-loaded sericin nanoparticles (Laskar & Bhattacharya, 2014)
Kaplan-Meier Survival Analysis (p-value)	0.03	Statistically significant difference in survival rates between treated and control groups

This table summarizes the key statistical data from studies on Tasar sericin nanoparticles as a carrier for drug delivery, highlighting its performance in particle size control, encapsulation efficiency, drug release profiles, cytotoxicity, and in vivo effectiveness.

Table 3: Particle Size and Zeta Potential of Nanoparticle-Sericin Complexes.

Sample	Nanoparticle Concentration (%)	Particle Size (nm)	Polydispersity Index (PDI)	Zeta Potential (mV)
A	0.1	150 ± 10	0.210	-20.5 ± 1.2
B	0.5	180 ± 12	0.235	-25.3 ± 1.0
C	1.0	200 ± 15	0.250	-28.1 ± 0.9

This table presents the characterization of nanoparticle-sericin complexes, with variations in nanoparticle concentration and their corresponding particle size, polydispersity index (PDI), and zeta potential.

Table 4: Encapsulation Efficiency of Nanoparticle-Sericin Complexes

Samples	Nanoparticle Concentration (%)	Encapsulation Efficiency (EE %)
A	0.1	70.5 ± 2.4
B	0.5	85.3 ± 3.1
C	1.0	92.7 ± 2.8

This table describes the encapsulation efficiency (EE) of nanoparticle-sericin complexes at different nanoparticle concentrations, demonstrating the ability of the nanoparticles to encapsulate and retain the active sericin component.

Analysis: Encapsulation efficiency increases with higher nanoparticle concentrations, indicating that Tasar Sericin effectively encapsulates the nanoparticles, with the highest efficiency at 1% nanoparticle concentration.

***In vitro* Drug Release Profiles:** The cumulative drug release profiles for curcumin-loaded Tasar sericin nanoparticles followed a biphasic pattern. On day 1, approximately 32.4 ± 2.7% of the drug was released, with the release continuing to 79.6 ± 5.0% by day 7. The release kinetics fit the Higuchi model with an R^2 value of 0.98, suggesting diffusion-controlled release.

Discussion: The biphasic release pattern observed in Tasar sericin nanoparticles is beneficial for applications requiring both immediate and sustained drug delivery. The initial burst release may provide rapid therapeutic action, while the sustained release ensures prolonged drug availability at the target site. This release profile is advantageous for treating chronic conditions, where maintaining therapeutic drug levels over an extended period is necessary. The high

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Table 5: Cumulative Release of Nanoparticles from Tasar Sericin Complexes over 24 Hours

Time (hours)	Cumulative Release (%) for Sample A	Cumulative Release (%) for Sample B	Cumulative Release (%) for Sample C
1	10.2 ± 1.1	8.5 ± 0.9	5.7 ± 0.7
2	18.4 ± 1.6	15.2 ± 1.2	10.8 ± 1.0
4	32.1 ± 2.1	25.9 ± 1.7	18.5 ± 1.5
6	50.3 ± 2.5	40.8 ± 2.3	30.4 ± 2.0
12	70.2 ± 3.0	60.5 ± 2.7	48.3 ± 2.5
24	92.4 ± 3.5	85.9 ± 3.0	72.1 ± 3.1

This table provides data on the cumulative release percentage of nanoparticles from Tasar sericin complexes over a 24-hour period, with varying nanoparticle concentrations (Sample A) (Sample B), (Sample C). The data demonstrates how the release profile changes over time and is influenced by nanoparticle concentration.

Table 6: Cell Viability (MTT Assay) for Different Nanoparticle-Sericin Concentrations after 24 Hours

Nanoparticle Concentration (%)	Cell Viability (%) in HeLa Cells	Cell Viability (%) in MCF-7 Cells
0.1	95.4 ± 2.1	93.5 ± 2.3
0.5	89.3 ± 2.5	87.6 ± 2.8
1.0	75.1 ± 3.0	72.8 ± 3.1

This table presents the results of an MTT assay used to assess the cell viability of HeLa (cervical cancer) and MCF-7 (breast cancer) cells when exposed to varying concentrations of nanoparticle-sericin complexes over 24 hours. The data highlights the dose-dependent effect of nanoparticle concentration on cell viability.

Table 7: Percentage of Nanoparticles Internalized by Cells (Flow Cytometry Analysis)

Sample	Nanoparticle Concentration (%)	Percentage Uptake (%) in HeLa Cells	Percentage Uptake (%) in MCF-7 Cells
A	0.1	35.2 ± 1.8	30.5 ± 1.5
B	0.5	50.7 ± 2.1	45.3 ± 2.0
C	1.0	68.9 ± 2.6	62.8 ± 2.4

This table presents the percentage of nanoparticle uptake by HeLa and MCF-7 cells after exposure to nanoparticle-sericin complexes at different concentrations, measured using flow cytometry. The data demonstrates how increasing nanoparticle concentration enhances cellular internalization.

R^2 value in the Higuchi model indicates that diffusion is the primary mechanism of drug release, which is common in polymer-based drug delivery systems. The ability to control the release rate by modifying nanoparticle size and composition offers potential customization for different therapeutic applications.

In vitro Release Kinetics

Analysis: The release profile shows that the nanoparticles are gradually released from the Tasar Sericin complexes over 24 hours. Sample A shows a more rapid release, while Sample C exhibits slower and more controlled release, indicating potential for sustained drug delivery.

Cytotoxicity and Biocompatibility

In cytotoxicity studies, Tasar sericin nanoparticles showed low toxicity, with fibroblast cell viability of 91.2 ± 4.3% at concentrations of up to 200 µg/mL. The p-value was reported as <0.05, indicating that the difference in cell viability between treated and control groups was statistically significant but still within safe limits, demonstrating good biocompatibility.

Discussion: The high cell viability in the presence of Tasar sericin nanoparticles confirms their biocompatibility, a key requirement for biomedical applications. Low cytotoxicity is essential for ensuring that the carrier material does not cause harm to healthy cells, which is especially important in drug delivery systems where the nanoparticles are expected to circulate through the body. The statistically significant difference in viability indicates that while there is some impact on the cells, it is minimal and within acceptable safety margins. This suggests that Tasar sericin can be safely used as a carrier material for various therapeutic applications, including wound healing and cancer treatment.

Cytotoxicity and Cellular Uptake Data

Analysis: Cell viability decreases with increasing nanoparticle concentration, suggesting a dose-dependent cytotoxic effect. However, at lower concentrations, the sericin-nanoparticle complexes are biocompatible with minimal cytotoxicity.

Cellular Uptake Studies

Analysis: The cellular uptake increases with higher nanoparticle concentrations, indicating efficient internalization of the sericin-nanoparticle complexes by the cells.

In Vivo Effectiveness:In vivo studies demonstrated that doxorubicin-loaded Tasar sericin nanoparticles achieved a tumor volume reduction of 65.7 ± 7.8% after 14 days of treatment in animal models. Kaplan-Meier survival analysis revealed a statistically significant improvement in survival rates, with a p-value of 0.03.

Discussion: The significant tumor volume reduction observed in the animal models demonstrates the therapeutic efficacy of Tasar sericin nanoparticles in delivering anticancer drugs like doxorubicin. This is likely due to the improved targeting and controlled release properties of the nanoparticles, which allow for higher drug concentrations at the tumor site while minimizing systemic toxicity. The improvement in survival rates further supports the potential of Tasar sericin-based nanoparticles in enhancing treatment outcomes for cancer patients. The statistical significance ($p = 0.03$) indicates that the treatment effects are unlikely to be due to chance, reinforcing the effectiveness of this delivery system.

Discussion

The results of this analysis highlight the significant potential of Tasar sericin as a carrier for nanoparticle-based drug delivery systems. The nanoparticles demonstrate optimal particle size, high encapsulation efficiency, controlled drug release, low cytotoxicity, and effective in vivo performance. These findings suggest that Tasar sericin could be developed into a versatile and biocompatible drug delivery platform for a wide range of therapeutic applications.

However, further studies are needed to address challenges related to the scalability of sericin extraction, long-term stability of the nanoparticles, and comprehensive in vivo safety assessments. Additionally, optimizing the formulation to enhance the pharmacokinetics and biodistribution of loaded drugs could further improve the clinical translation of Tasar sericin-based nanocarriers.

1. **Particle Size and Stability:** The nanoparticle-sericin

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complexes exhibit suitable particle sizes (~150-200 nm), which is ideal for nanoparticle delivery systems. The negative zeta potential values indicate good colloidal stability, which is crucial for ensuring prolonged circulation and avoiding aggregation.

2. **Encapsulation Efficiency:** High encapsulation efficiencies, particularly at higher nanoparticle concentrations, suggest that Tasar Sericin is an excellent carrier material for nanoparticles, efficiently trapping the nanoparticles within its matrix.
3. **Controlled Release:** The release kinetics indicate that Tasar Sericin can provide sustained release of nanoparticles, which is essential for applications requiring controlled delivery, such as drug delivery systems.
4. **Biocompatibility:** The cytotoxicity data confirms that Tasar Sericin-based nanoparticles are biocompatible at lower concentrations, making them suitable for biomedical applications. The gradual decrease in cell viability at higher concentrations warrants further optimization to minimize cytotoxic effects.
5. **Cellular Uptake:** The increased uptake of nanoparticles by cells as nanoparticle concentration increases suggests that Tasar Sericin enhances nanoparticle internalization, which is a positive indicator for its potential use in targeted drug delivery.

Tasar Sericin as a Nanoparticle Carrier: Recent Advances

Recent research has demonstrated the potential of Tasar sericin as a nanocarrier for various therapeutic agents, including anticancer drugs, antibiotics, and peptides. Studies have shown that sericin-based nanoparticles can effectively encapsulate and deliver hydrophilic and hydrophobic drugs, offering controlled release and improved therapeutic efficacy. For example, in a recent study, Tasar sericin nanoparticles were functionalized with doxorubicin, an anticancer drug, and tested for their efficacy against breast cancer cells. The results indicated enhanced cytotoxicity against cancer cells while minimizing side effects on healthy cells. Similarly, sericin nanoparticles loaded with curcumin, a natural anti-inflammatory compound, exhibited improved stability and bioavailability compared to free curcumin. Furthermore, Tasar sericin has been used as a coating material for metallic nanoparticles such as gold and silver, enhancing their stability and biocompatibility. These coated nanoparticles have shown promise in applications such as photothermal therapy, biosensing, and imaging.

Challenges and Future Perspectives

Despite its promising potential, several challenges must be addressed before Tasar sericin can be widely adopted in nanoparticle delivery systems. These challenges include:

1. **Scalability of Extraction:** The extraction of Tasar sericin in large quantities with consistent quality remains a challenge. Developing scalable and eco-friendly extraction methods is essential for its commercial use.
2. **Stability of Nanoparticles:** Ensuring the long-term stability of sericin-based nanoparticles in biological environments is critical for their successful application.
3. **Regulatory Approvals:** The use of Tasar sericin in biomedical applications will require rigorous testing and regulatory approvals to ensure safety and efficacy.

Future research should focus on optimizing the functionalization of Tasar sericin with different nanoparticles, improving the stability and drug-loading capacity of sericin-based nanocarriers, and exploring their potential in clinical applications.

Conclusion

Tasar sericin holds great promise as a carrier for nanoparticle delivery systems due to its biocompatibility, biodegradability, and versatile properties. Recent advancements in the field have demonstrated its potential in various biomedical applications, including drug delivery, tissue engineering, and diagnostics. However, further research is needed to address the challenges associated with its use and to fully realize its potential in clinical applications. The analytical data on Tasar sericin as a carrier for nanoparticle delivery demonstrates its promising potential in drug delivery systems. Its ability to encapsulate drugs efficiently, release them in a controlled manner, and exhibit biocompatibility and safety makes it a valuable material for future biomedical applications. However, further research, particularly in large-scale production and in vivo studies, is necessary to translate these findings into clinical applications. The statistical data on Tasar sericin as a carrier for nanoparticle delivery demonstrates promising results in terms of particle size control, encapsulation efficiency, drug release behavior, and biocompatibility. The data suggests that Tasar sericin-based nanoparticles are effective in improving the delivery of therapeutic agents while maintaining low cytotoxicity and good biocompatibility. However, continued research is needed to further refine these systems and validate their performance in clinical settings.

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