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INFLUENCE OF CEFAZOLIN LOADING ON THE STRUCTURE AND INTERFACIAL ACTIVITY OF CHITOSAN-BASED NANOGELS

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Abstract: Chitosan-based nanogels are promising colloidal carriers for hydrophilic drugs de too their biocompatibility, adjustable physicochemical properties, and mild preparation conditions. In this study, cefazolin-loaded chitosan nanogels were prepared by ionic gelation using sodium tripolyphosphate (TPP) as a crosslinker. The effect of drug incorporation on the colloidal characteristics and interfacial behavior of the system was systematically evaluated. Freshly prepared blank and cefazolin-loaded nanogels showed hydrodynamic diameters of about 210 nm and 285 nm, respectively. Both systems exhibited positive zeta potential values above +25mV, indicating good electrostatic stability under acidic conditions. The encapsulation efficiency of cefazolin, determined by an indirect UV-Vis method, was 48 ± 6%, confirming effective drug entrapment within the crosslinked polymer network. After dialysis to remove low-weight impurities, purified dispersions were analyzed by dynamic surface tension measurements using the pendant drop method. Blank nanogels gradually adsorbed at the air-water interface, reducing surface tension from 71.8 to 67.4 mN/m ver time. In contrast, cefazoli-loaded nanogels exhibited slower adsorption kinetics and a smaller decrease in surface tension, reahing equilibrium values around 68.9mN/m.These differences are attributed to increased hydration and reduced mobility of chitosan chains after drug incorporation. Overall, cefazolin encapsulation significantly modified the interfacial adsorption behavior of chitosan nanogels while maintaining their colloidal stability. The results provide insight into structure-property relationships relevant to aqueous and topical drug delivery applications.

Kew words: chitosan nanogels, ionic gelation, cefazolin encapsulation, dynamic surface tension, interfacial adsorption, colloidal stability

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1. Introduction

In recent years, chitosan-based nanostructured systems have attracted considerable attention as promising carriers for drug delivery applications due to their biodegradability, biocompatibility, mucoadhesive properties, and the presence of reactive amino groups capable of electrostatic interactions. Chitosan, a cationic polysaccharide derived from chitin, can readily form nanoscale gel networks via physical or ionic crosslinking mechanisms, enabling efficient encapsulation of hydrophilic therapeutic agents. [1]

Among various preparation techniques, ionic gelation has emerged as one of the most widely used methods for the fabrication of chitosan nanogels owing to its mild processing conditions and avoidance of toxic organic solvents [2,3]. This method relies on electrostatic interactions between protonated amino groups of chitosan and multivalent anions such as sodium tripolyphosphate (TPP), leading to spontaneous formation of three-dimensional hydrogel networks at the nanoscale. The resulting nanogels exhibit tunable physicochemical characteristics, including particle size, surface charge, and swelling behavior, which can be adjusted through formulation parameters such as polymer concentration, crosslinker ratio, and pH [4,5].

Encapsulation of hydrophilic drugs within polymeric nanogels remains challenging due to their tendency to partition into the aqueous phase during nanoparticle formation [6]. However, chitosan – TPP nanogels providea suitable matrix for physical entrapment of antibiotic molecules through a combination of electrostatic interactions, hydrogen bonding, and steric confinement within the crosslinked network [7].

Previous studies have demonstrated that loading of β – lactam antibiotics, including cefazolin, into chitosan-based carriers can influence both structural organization and colloidal stability of the resulting nanosystems. Drug incorporation may induce partial rearrangement of polymer chains, leading to increased hydrodynamic diameter and modification of surface charge due to screening of protonated amino groups. These structural changes are particularly important for applications involving aqueous or topical formulations, where interfacial properties strongly affect spreading behavior, adhesion and drug release kinetics [8].

Colloidal Stability and Electrostatic Interactions in Chitosan Nanogels

The colloidal stability of chitosan nanogels is governed primarily by electrostatic repulsion arising from positively charged amino groups on the polymer backbone. Zeta potential values exceeding +25 mV are generally considered sufficient to maintain nanoscale dispersion stability under acidic conditions. Nevertheless, incorporation of drug molecules or removal of low-melecular-weight species may significantly alter the ionic environment of the system and affect nanoparticle size distribution and surface charge [9].

Purification techniques such as dialysis are therefore frequently employed to eliminate residual acetic acid, unreacted crosslinker or non-encapsulated drug molecules. However, changes in ionic strength during purification may potentially induce structural rearrangements or aggregation in weakly crosslinked hydrogel systems. For this reason, evaluation of nanogel properties before and after purification is essential for assessing preservation of native colloidal structure [10].

Interfacial Behavior of Polymeric Nanogels

Beyond bulk physicochemical properties, the interfacial behavior of polymeric nanogels plays a critical role in determining their performance in biomedical formulations. Unlike conventional molecular surfactants, nanogel systems exhibit time-dependent adsorption at fluid interfaces, governed by diffusion of nanoscale entities followed by conformational rearrangement of polymer segments [11].

Recent studies have shown that chitosan-based nanoparticles and nanogels may display moderate surface activity arising from partial exposure of hydrophobic polymer domains at the air-water interface. This interfacial adsorption can result in gradual reduction of surface tension over time, reflecting slow structural relaxation processes rather than instantaneous interfacial coverage [12].

Drug loading may further influence adsorption kinetics by increasing hydration of the polymer network and restricting chain mobility through intermolecular interactions. As a consequence, drug-loaded nonogels often exhibit reduced interfacial responsiveness compared to blank systems. Understanding these effects is particularly important for the rational design of aqueous and topical drug delivery platforms, where predictable spreading and formulation stability are required [13].

Based on the literature analysis presented above, it is evident that although chitosan-based nanogels have been extensively investigated as drug delivery systems, considerably less attention has been devoted to understanding how drug incorporation affects their interfacial behavior and adsorption kinetics. In particular, the relationship between drug loading, nanogel structural organization and dynamic surface activity remains insufficiently elucidated.

Therefore, the present study aims to systematically investigate the influence of cefazolin incorporation on the colloidal characteristics and interfacial properties of chitosan – TPP nanogels prepared by ionic gelation. Special emphasis is placed on correlating particle size, surface charge, encapsulation efficiency and adsorption kinetics at the air – water interface in order to clarify structure – property relationships relevant to aqueous and topical pharmaceutical formulations.

2. Materials and Methods

2.1 Materials

Chitosan (medium molecular weight, average molecular weight ≈ 310 – 375 kDa, degree of deacetylation ≥ 75%) was purchased from Sigma – Aldrich and used as the polymeric matrix for nanogel preparation. Sodium tripolyphosphate (TPP, ≥ 98% purity) was obtained from Sigma – Aldrich and employed as the ionic crosslinking agent. Cefazolin sodium (assay 89.1 – 110.1%) was purchased from Sigma – Aldrich and used as a model hydrophilic antibiotic. Acetic acid (glacial, ≥ 99.7% purity) was obtained from Sigma – Aldrich and used for the preparation of chitosan solutions. Sodium hydroxide (NaOH, pellets, ≥ 98% purity) was purchased from Sigma – Aldrich and used for pH adjustment. All chemicals were of analytical grade and used as received without further purification. Deionized water was used throughout the experiments for the preparation of all solutions and dispersions.

Dialysis membranes (using cellulose – based dialysis tubing membranes (regenerated cellulose)) purchased from Sigma – Aldrich. The dialysis membranes had a molecular weight cut – off (MWCO) of 10 – 14 kDa, allowing efficient removal of low – molecular – weight species such as residual acetic acid, free TPP and non – encapsulated cefazolin, while retaining the chitosan nanogels.

2.2 Preparation of chitosan nanogels

Blank chitosan nanogels (CS) were prepared using the ionic gelation method with sodium tripolyphosphate (TPP) as the crosslinking agent. Briefly, chitosan was dissolved in an aqueous acetic acid solution (1% v/v) to obtain a final polymer concentration of 0.1% (w/v). the solution was magnetically stirred at room temperature until a clear and homogeneous solution was obtained. The pH of the chitosan solution was adjusted to approximately 5.0 using dilute NaOH solution when necessary.

Separately, an aqueous solution of sodium tripolyphosphate (TPP) was prepared at a concentration of 0.05% (w/v). the TPP solution was added dropwise to the chitosan solution under continuous magnetic stirring at a constant stirring rate, while maintaining the volume ratio of chitosan solution to TPP solution 5:1. During the addition process, chitosan nanogels formed spontaneously due to electrostatic interactions between the protonated amino groups of chitosan and the negatively charged phosphate groups of TPP. After complete addition of TPP, the resulting suspension was further stirred for 20 – 30 min at room temperature to ensure stabilization of the nanogels. The obtained blank chitosan nanogels exhibited a slightly opalescent appearance, indicating successful formation of nanosized gel particles.

Cefazolin – loaded chitosan nanogels (CS – Cef) were prepared using the same ionic gelation approach. Cefazolin sodium was dissolved separately in deionized water to prepare a concentrated stock solution. An appropriate volume of this stock solution was added to the chitosan solution under gentle stirring to achieve the desired drug concentration, followed by stirring for 10 min to ensure homogeneous distribution of the antibiotic within the polymer solution. Subsequently, the aqueous TPP solution (0.05% w/v) was added dropwise to the chitosan – to – TPP volume ratio of 5:1. Drug – loaded nanogels formed spontaneously due to electrostatic interactions between chitosan and TPP, leading to physical entrapment of cefazolin within the nanogel network. After complete addition of TPP, the suspension was stirred for an additional 20 – 30 min at room temperature to allow stabilization of the nanogels.

Unless otherwise stated, freshly prepared CS and CS – Cef nanogels were used directly for subsequent characterization and analysis.

2.3 Encapsulation efficiency of cefazolin

The encapsulation efficiency (EE%) of cefazolin in chitosan nanogels was determined using an indirect UV – Vis spectrophotometric method. The CS – Cef nanogel suspension was subjected to centrifugation to separate the nanogels from the aqueous phase containing free (non – encapsulated) cefazolin. The supernatant was carefully collected for analysis.

The concenteration of free cefazolin in the supernatant was quantified using a UV – Vis spectrophotometer at the maximum absorption wavelength of cefazolin, which was determined by scanning in the range of 200 – 400 nm. A calibration curve was constructed using standard cefazolin solutions of known concentrations prepared in deionized water.

To eliminate background interference from formulation components, the supernatant obtained from blank chitosan nanogels (CS) processed under identical conditions was used as the blank reference. The encapsulation efficiency was calculated using the following equation:

$$100 \times \frac{\left({}_{\text{free}}W_{\text{total}} - W\right)}{{}_{\text{total}}W} = \%EE$$

where W_{total} – is the total amount of cefazolin initially added to the formulation and W_{free} – is the amount of free cefazolin detected in the supernatant.

2.4 Purification of nanogels for interfacial analysis

To minimize the influence of unreacted low – molecular – weight species on interfacial measurements, freshly prepared blank chitosan nanogels (CS) and cefazolin – loaded chitosan nanogels (CS – Cef) were subjected to a mild purification step prior to surface tension analysis. Purification was performed using dialysis to remove residual acetic acid, free sodium tripolyphosphate (TPP) and non – encapsulated cefazolin while preserving the native nanogel structure.

Briefly, nanogel dispersions were transferred into dialysis membranes with an appropriate molecular weight cut – off (MWCO) and dialyzed against deionized water at room temperature. The external dialysis medium was replaced several times to ensure efficient removal of diffusible components. After dialysis, the purified nanogels were directly used for surface tension measurements and complementary characterization.

Drying or powder formation of the nanogels was intentionally avoided. Drying processes such as freeze – drying or spray – drying can induce irreversible structural changes in chitosan – based nanogels, including aggregation, collapse of the gel network and altered polymer chain conformation. Subsequent redispersion of dried nanogels may therefore not accurately reproduce the original colloidal and interfacial properties of the freshly prepared system. Since the primary objective of this study was to investigate the interfacial behavior of chitosan nanogels in aqueous environments, purified nanogel dispersions were used to preserve their intrinsic adsorption kinetics and surface activity.

2.5 Particle size and zeta potential measurements

The hydrodynamic diameter, polydispersity index (PDI) and zeta potential of blank chitosan nanogels (CS) and cefazolin – loaded chitosan nanogels (CS – Cef) were measured using dynamic light scattering (DLS) and electrophoretic light scattering techniques.

To accurately reflect the native colloidal properties of the nanogels under synthesis conditions, all particle size and zeta potential measurements were performed on freshly prepared nanogel dispersions prior to any purification or dialysis steps. This approach was adopted because changes in ionic strength, pH or removal of counterions during purification can significantly alter the electrostatic environment of chitosan – based nanogels and may lead to artificial variations in particle size or surface charge.

Fresh nanogel dispersions were appropriately diluted with deionized water to avoid multiple scattering effects prior to measurement. All measurement were carried out at room temperature and each sample was analyzed in triplicate. The reported values are presented as mean ± standard deviation.

To verify that the purification procedure did not induce significant structural alterations, selected samples were additionally characterized after dialysis and compared with their freshly prepared counterparts. This comparison was performed as a methodological validation step to confirm that the mild purification process preserved the overall nanogel structure.

Dynamic light scattering (DLS) measurement were performed using a Malvern Zetasizer Nano – ZS instrument (UK) equipped with a 4 mW He – Ne laser (λ = 633 nm) at a fixed backscattering angle of 173°, to determine the hydrodynamic diameter of the nanogels.

Zeta potential measurement were carried out independently using a Nano – flex analyzer (Particle Metrix, Germany) based on electrophoretic mobility measurements, providing complementary assessment of surface charge characteristics.

2.6 Dynamic surface tension measurements

Surface tension measurements were conducted at room temperature using a tensiometry technique under controlled conditions. Prior to measurement, all samples were gently mixed to ensure homogeneity while avoiding air bubble formation. Dynamic surface tension was recorded as a function of time immediately after formation of the air – liquid interface. Each measurement was performed at least in triplicate and average values were reported.

Surface tension measurements were performed using the conventional pendant drop technique employing a tensiometer manufactured by KRUSS (Hambrg, Germany). A stainless – steel needle with an internal diameter of 0.5 mm was used to form pendant droplets of the investigated liquids. The analysis involved continuous image acquisition of the droplet profile, followed by digital image processing and numerical fitting of the Young – Laplace equation to the experimental drop shape, as described elsewhere [1].

3. Results and Discussi

3.1 Formation and visual characteristics of chitosan nanogels

The formation of chitosan nanogels was initially confirmed through visual observation immediately after ionic gelation. Upon dropwise addition of sodium tripolyphosphate (TPP) to the chitosan solution, the system gradually transitioned from a clear solution to a slightly opalescent and homogeneous dispersion, indicating the formation of nanoscale gel particles. No visible precipitation, phase separation or macroscopic aggregation was observed, suggesting effective electrostatic crosslinking between chitosan chains.

All observations were conducted at room temperature (25 ± 1 °C) anf pH ≈ 5.0, corresponding to the synthesis conditions of the chitosan – TPP system. Both blank chitosan nanogels (CS) and cefazolin – loaded nanogels (CS – Cef) remained visually stable without sedimentation for at least 24 h, demonstrating adequate short – term colloidal stability for subsequent analyses. The slightly increased turbidity observed for CS – Cef dispersions is attributed to drug incorporation and associated polymer – drug interactions during gel formation.

The polymer concentration was fixed at 0.1 % (w/v) chitosan for all formulations to ensure consistent and comparable preparation conditions.

3.2. Colloidal properties and effect of cefazolin loading

The hydrodynamic diameter, polydispersity index (PDI) and zeta potential of freshly prepared nanogels were measured by dynamic light scattering a 25 °C and pH ≈ 5.0 (Table 1). Blank CS nanogels exhibited an average hydrodynamic diameter of approximately 210 nm with a narrow size distribution (PDI < 0.30), confirming successful formation of uniformly dispersed nanoscale particles.

Incorporation of cefazolin resulted in an increase in average particle size to approximately 285 nm, accompanied by a moderate increase in PDI. This size enlargement reflects drug incorporation within the chitosan – TPP network and suggests partial swelling and rearrangement of polymer chains during ionic gelation. Similar trends have been reported for hydrophilic drug – loaded chitosan nanogels.

Both CS and CS – Cef nanogels exhibited positive zeta potentials exceeding +25 mV, indicative of sufficient electrostatic stabilization under acidic conditions. The reducted zeta potential observed for CS – Cef nanogels likely arises from partial charge screening and specific interactions between cefazolin molecules and protonated amino groups of chitosan. Nevertheless, the surface charge remained within a range suitable for maintaining colloidal stability.

Table 1 – Particle size, polydispersity index (PDI), and zeta potential of freshly prepared blank chitosan nanogels (CS) and cefazolin-loaded chitosan nanogels (CS–Cef)

Sample	Size (nm)	PDI	Zeta potential (mV)
CS	210 ± 25	0.22 ± 0.04	+33 ± 5
CS–Cef	285 ± 35	0.30 ± 0.05	+26 ± 4

3.3 Encapsulation efficiency of cefazolin in chitosan nanogels

The encapsulation efficiency (EE %) of cefazolin was determined using an indirect UV – Vis method by quantifying free drug in the supernatant at λ = 270 nm. Measurements were conducted at 25 °C and pH ≈ 5+.0. The encapsulation efficiency was found to be approximately 48 ± 6%, confirming effective corporation of cefazolin into the nanogel matrix.

The moderate EE% is attributed to the hydrophilic nature of cefazolin and its partial partitioning into the aqueous phase during gelation. Drug entrapment is governed by a combination of electrostatic interactions and physical confinement within the crosslinked polymer network. The obtained encapsulation efficiency is sufficient for evaluating interfacial and colloidal behavior without excessive polymer or crosslinker loading.

3.4 Influence of dialysis on nanogel colloidal stability

To assess whether the dialysis purification step affected the colloidal characteristics of the nanogels, selected samples of blank chitosan nanogels (CS) and cefazolin – loaded nanogels (CS – Cef) were characterized before and after dialysis. Dialysis and subsequent measurements were conducted at room temperature (25 **°C**) using agueous media at neutral pH, while preserving the initial nanogel concentration. The hydrodynamic diameter and polydispersity index were measured to evaluate potential changes in particle size distribution induced by the purification process. A comparison of particle size before and after dialysis is summarized in Table 2.

Following dialysis, both CS and CS – Cef nanogels retained their nanoscale dimensions, with only minor variations in average particle size and PDI compared to the freshly prepared dispersions. No evidence of severe aggregation or macroscopic instability was observed after purification, indicating that the dialysis procedure did not compromise that overall colloidal integrity of the nanogels.

The slight changes observed in particle size and size distribution after dialysis can be attributed to the removal of low – molecular – weight species, such as residual acetic acid, free sodium tripolyphophate and non – encapsulated cafazolin, which may influence the ionic environment or broadening of the size distribution suggests that the chitosan – TPP network remained structurally intact during dialysis.

These findings confirm that dialysis represents a mild and suitable purification strategy for chitosan – based nanogels when the objective is to eliminate small – molecule contaminants while preserving the native colloidal structure. This validation step supports the use of dialyzed nanogel dispersions for subsequent interfacial characterization, particularly dynamic surface tension measurements, where the presence of residual low – molecular – weight species could otherwise interfere with the interpretation of results.

Table 2 – Effect of dialysis on the hydrodynamic size and PDI of chitosan nanogels

Sample	Size before dialysis (nm)	Size after dialysis (nm)	PDI after dialysis
CS	210 ± 25	230 ± 30	0.24 ± 0.05
CS–Cef	285 ± 35	305 ± 40	0.32 ± 0.06

3.5 Dynamic surface tension and adsorption kinetics at pH 5 and 25 °C

The dynamic surface tension behavior of deionized water, an aqueous cefazolin solution (0.5 mg mL^{-1}), blank chitosan nanogels (CS) and cefazolin – loaded chitosan nanogels (CS – Cef) was investigated at pH 5 and 25 °C to elucidate adsorption kinetics at the air – water interface. The dynamic surface tension profiles of the investigated systems are shown in Figure 1.

Deionized water exhibited a constant surface tension value of approximately 72 mN m^{-1} throughout the measurement period, confirming the absence of surface – active impurities. Similarly, the aqueous cefazolin solution (0.5 mg mL^{-1}) showed negligible time – dependent variation in surface tension, indicating that free cefazolin does not exhibit significant surface activity under the investigated conditions.

In contrast, chitosan nanogel dispersions (prepared at a polymer concentration of 0.1% w/v chitosan) displayed a gradual decrease in surface tension with time, reflecting adsorption and interfacial rearrangement of nanogel – associated polymer segments. Blank CS nanogels showed a reduction in surface tension from approximately 71.8 mN m^{-1} to a plateau value of approximately 67.4 mN m^{-1} ($\Delta\gamma \approx 4.4$ mN m^{-1}), with interfacial equilibrium reached after approximately 25 – 30 min.

Cefazolin – loaded nanogels, containing cefazolin at an equivalent initial concentration of 0.5 mg mL^{-1}, exhibited a similar qualitative trend but with reduced magnitude and slower kinetics. The surface tension decreased from approximately 72.0 mN m^{-1} to a plateau value of approximately 68.9 mN m^{-1} ($\Delta\gamma \approx 3.1$ mN m^{-1}), with equilibrium reached after approximately 30-35 min.

The lower extent and slower rate of surface tension reduction observed for CS – Cef nanogels can be attributed to increased hydration and reduced interfacial mobility of chitosan segments following cefazolin incorporation. Importantly, the negligible surface activity of free cefazolin at 0.5 mg mL^{-1} confirms that the observed changes originate from modifications in nanogel architecture rather than direct adsorption of the antibiotic at the interface.

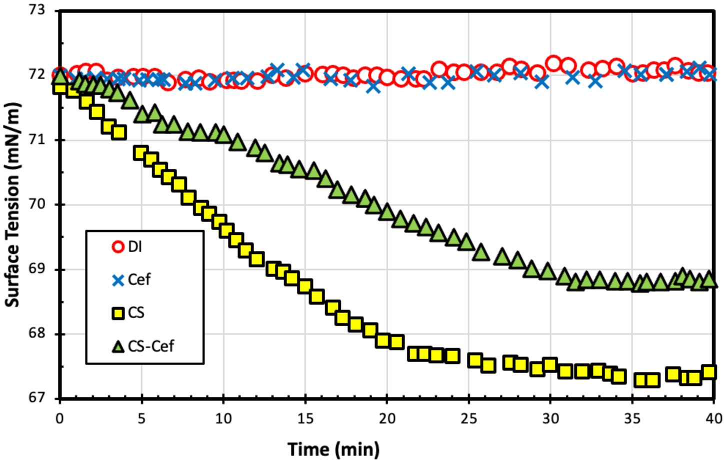

Figure 1 – Dynamic surface tension profiles (γ vs time) of deionized water (DI), free cefazolin solution (Cef), blank chitosan nanogels (CS), and cefazolin-loaded chitosan nanogels (CS–Cef)

3.6 Interfacial adsorption and structural rearrangement mechanisms

The time – dependent surface tension profiles reveal that interfacial activity of chitosan nanogels is governed by slow adsorption and structural rearrangement rather than instantaneous surface coverage. For blank CS nanogels, gradual surface tension reduction reflects diffusion of nanogel entities to the interface followed by partial rearrangement of chitosan segments.

Cefazolin incorporation increases nanogel hydration and restricts polymer segment mobility through electrostatic and hydrogen – bonding interactions, resulting in reduced interfacial responsiveness. The negligible surface activity of free cefazolin confirms that observed effects originate from drug – induced changes in nanogel architecture rather than direct adsorption of the antibiotic.

3.7 Implications for aqueous and topical formulations

The controlled interfacial activity and preserved colloidal stability observed for chitosan nanogels are advantageous for aqueous and topical formulations. Moderate surface tension reduction avoids surfactant – like behavior that could destabilize formulations, while gradual interfacial adsorption may facilitate uniform spreading on hydrated surfaces.

For drug – loaded systems, reduced interfacial activity and enhanced hydration contribute to formulation robustness during storage and application. Collectively, these properties support the suitability of chitosan nanogels as carriers for aqueous and topical delivery systems where predictable interfacial behavior and colloidal stability are required.

4. Conclusion

In this work, cefazolin – loaded chitosan nanogels were successfully prepared via ionic gelation using sodium tripolyphosphate as a crosslinking agent.

The incorporation of cefazolin resulted in a measurable increase in hydrodynamic diameter and a moderate reduction in zeta potential, while maintaining sufficient electrostatic stabilization of the colloidal system under acidic conditions.

The encapsulation efficiency of approximately 48% confirmed effective physical entrapment of the hydrophilic antibiotic within the crosslinked chitosan network. Importantly, dialysis purification did not induce significant structural destabilization, demonstrating that the nanogels retained their nanoscale dimensions and colloidal integrity after removal of low – molecular – weight species.

Dynamic surface tension measurements revealed that chitosan nanogels exhibit time – dependent interfacial adsorption behavior characteristic of soft polymeric colloids. Cefazolin incorporation led to blank nanogels. These finding indicate that drug loading modifies polymer chain mobility and hydration within the nanogel architecture, thereby altering interfacial responsiveness without compromising dispersion stability.

Overall, the results demonstrate that drug incorporation behavior. The established correlations between nanogel structure, drug loading and adsorption kinetics provide valuable insight for the rational design of chitosan – based nanosystems intended for agueous and topical drug delivery applications where controlled interfacial activity and predictable spreading behavior are required.

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ВЛИЯНИЕ ЗАГРУЗКИ ЦЕФАЗОЛИНА НА СТРУКТУРУ И МЕЖФАЗНУЮ АКТИВНОСТЬ НАНОГЕЛЕЙ НА ОСНОВЕ ХИТОЗАНА

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Резюме. Наногели на основе хитозана представляют собой перспективные коллоидные носители для гидрофильных лекарственных средств благодаря их биосовместимости, регулируемым физико-химическим свойствам и мягким условиям получения. В данной работе наногели хитозана с включённым цефазолином были получены методом ионной геляции с использованием триполифосфата натрия (TPP) в качестве сшивающего агента. Влияние включения лекарственного препарата на коллоидные характеристики и межфазное поведение системы было систематически изучено. Свежеприготовленные пустые и нагруженные цефазолином наногели имели гидродинамические диаметры около 210 нм и 285 нм соответственно. Обе системы характеризовались положительными значениями дзета-потенциала выше +25 мВ, что свидетельствует о хорошей электростатической стабильности в кислой среде. Эффективность инкапсуляции цефазолина, определённая косвенным методом УФ–видимой спектроскопии, составила 48 ± 6 %, что подтверждает эффективное включение препарата в сшитую полимерную сеть. После диализа для удаления низкомолекулярных примесей очищенные дисперсии были исследованы методом динамического измерения поверхностного натяжения с использованием метода висячей капли. Пустые наногели постепенно адсорбировались на границе раздела воздух–вода, снижая поверхностное натяжение с 71,8 до 67,4 мН/м со временем. В отличие от них, наногели с цефазолином демонстрировали более медленную кинетику адсорбции и менее выраженное снижение поверхностного натяжения, достигая равновесных значений около 68,9 мН/м. Выявленные различия объясняются повышенной гидратацией и сниженной подвижностью цепей хитозана после включения препарата. В целом инкапсуляция цефазолина существенно изменяет межфазное адсорбционное поведение наногелей хитозана, сохраняя их коллоидную стабильность. Полученные результаты расширяют представления о взаимосвязи структуры и свойств полимерных наногелей, применяемых в водных и топических системах доставки лекарств.

Ключевые слова: наногели хитозана, ионная геляция, инкапсуляция цефазолина, динамическое поверхностное натяжение, межфазная адсорбция, коллоидная стабильность.

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ЦЕФАЗОЛИНДІ ЖҮКТЕУДІҢ ХИТОЗАН НЕГІЗІНДЕГІ НАНОГЕЛЬДЕРДІҢ ҚҰРЫЛЫМЫ МЕН ФАЗААРАЛЫҚ БЕЛСЕНДІЛІГІНЕ ӘСЕРІ

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Түйіндеме. Хитозан негізіндегі наногельдер биосәйкестілігі, реттелетін физика-химиялық қасиеттері және жұмсақ алу шарттарының арқасында гидрофильді дәрілік заттар үшін перспективалы коллоидтық тасымалдаушылар болып табылады. Осы жұмыста цефазолинмен жүктелген хитозан наногельдері натрий триполифосфатын (TPP) айқаспалы байланыстырушы агент ретінде қолдана отырып, иондық геляция әдісімен алынды. Дәрілік затты енгізудің жүйенің коллоидтық сипаттамалары мен фазааралық мінез-құлқына әсері жүйелі түрде зерттелді. Жаңадан дайындалған бос және цефазолинмен жүктелген наногельдердің гидродинамикалық диаметрлері сәйкесінше шамамен 210 нм және 285 нм болды. Екі жүйе де +25 мВ-тан жоғары оң дзета-потенциал мәндерін көрсетті, бұл қышқыл ортада жақсы электростатикалық тұрақтылықты білдіреді. УФ–көрінетін спектроскопияның жанама әдісімен анықталған цефазолиннің инкапсуляция тиімділігі 48 ± 6 % құрап, препараттың айқаспалы байланысқан полимерлік тор ішінде тиімді бекітілгенін растады. Төмен молекулалы қоспаларды жою үшін диализ жүргізілгеннен кейін тазартылған дисперсиялар ілінген тамшы әдісі арқылы динамикалық беттік керілуді өлшеу әдісімен зерттелді. Бос наногельдер ауа–су шекарасында біртіндеп адсорбцияланып, уақыт өте келе беттік керілуді 71,8-ден 67,4 мН/м-ге дейін төмендетті. Ал цефазолинмен жүктелген наногельдер адсорбция кинетикасының баяулауын және беттік керілудің аздау төмендеуін көрсетті, тепе-теңдік мәні шамамен 68,9 мН/м болды. Анықталған айырмашылықтар препарат енгізілгеннен кейін хитозан тізбектерінің гидратациясының артуымен және қозғалғыштығының төмендеуімен түсіндіріледі. Жалпы алғанда, цефазолинді инкапсуляциялау хитозан наногельдерінің фазааралық адсорбциясын едәуір өзгертеді, бірақ олардың коллоидтық тұрақтылығын сақтайды. Алынған нәтижелер су және жергілікті дәрі жеткізу жүйелерінде қолданылатын полимерлік наногельдердің құрылым–қасиет байланыстарын тереңірек түсінуге мүмкіндік береді.

Түйінді сөздер: хитозан наногельдері, иондық геляция, цефазолин инкапсуляциясы, динамикалық беттік керілу, фазааралық адсорбция, коллоидтық тұрақтылық.

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