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Utilization of Chitosan as an Excipient in Pharmaceutical Formulations: Systematic Literature Review

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KEYWORDS
chitosan, pharmaceutical excipient, drug delivery, nanoformulation, sustainable pharmaceutical

ABSTRACT

Chitosan as a biodegradable polymer extracted from crustacean waste demonstrates significant potential as an innovative excipient in pharmaceutical formulations. This systematic literature review aims to analyze recent developments in chitosan utilization as pharmaceutical excipient based on scientific evidence from 2021-2025. Research methodology employed PRISMA 2020 approach with comprehensive search through PubMed, ScienceDirect, Scopus, and Web of Science databases. From 309 identified articles, 10 articles met inclusion criteria for in-depth analysis. Results indicate that chitosan possesses multifunctional advantages as excipient with superior mucoadhesive, biodegradable, and biocompatible properties. Chitosan applications in nanoformulations, tablets, mucoadhesive systems, and inhalation powders demonstrate high flexibility across various dosage forms. Co-processed excipient technology combining chitosan with other excipients produces optimal pharmacotechnical characteristics. Integration of chitosan in 3D printing technology and nanocarriers provides innovative solutions for controlled release and targeted drug delivery. Despite showing promising prospects, chitosan implementation as excipient still requires regulatory standardization and comprehensive method validation for large-scale industrial applications in pharmaceutical green chemistry.

INTRODUCTION

The modern pharmaceutical industry faces increasingly complex challenges in the development of effective, safe, and easy-to-manufacture drug preparations. One of the crucial components in the formulation of pharmaceutical preparations is the excipient, an additive that functions as a carrier, binder, or filler that provides the desired physicochemical properties to the medicinal product. In the development of pharmaceutical technology, there is a growing trend to explore natural materials that can serve as excipients with various advantages over conventional synthetic materials. Chitosan, a naturally occurring cationic polymer obtained from the deacetylation of chitin, has attracted significant attention in the pharmaceutical industry as a potential excipient. This polymer can be extracted from crustacean waste such as crab and shrimp shells, making it a sustainable and economical resource. Chitosan's unique properties as a cation-charged polysaccharide contribute to its good biocompatibility, high biodegradability, and low toxicity. In addition, the degree of deacetylation and the average molecular weight of chitosan can be controlled, resulting in a polymer with properties tailored for specific pharmaceutical applications (Abidin et al., 2024; Ramadhan et al., 2020; Varshosaz et al., 2015; You et al., 2016).

In the context of pharmaceutical applications, chitosan has been extensively researched as an excipient in various forms of medicinal preparations. Research shows that chitosan can be used in direct tablet compression, as a disintegrant, for the production of controlled-release forms of preparations, and to improve drug dissolution. Chitosan's mucoadhesive properties make it particularly suitable for drug delivery systems that require interaction with the mucosa, such as in oral, nasal, or ocular applications. Chitosan's ability to form permeable gels and

membranes also provides flexibility in the design of innovative drug carrier systems (Umar et al., 2020).

The advantages of chitosan as an excipient lie not only in its beneficial physicochemical properties but also in its safety and regulatory aspects. While interest in the use of chitosan as a pharmaceutical excipient through various routes of administration and for various applications is not new, there is still a need for an in-depth study of its safety aspects and the regulatory procedures required to include a new excipient in drug formulations. A comprehensive evaluation of chitosan's safety profile is particularly important given its broad application potential in the pharmaceutical industry. The development of nanopharmaceutical technology also provides a new dimension in the application of chitosan as an excipient. In recent decades, nanoformulations have increasingly become a valuable technology in drug carrier systems. Chitosan can be formulated into nanoparticles, microspheres, micelles, hydrogels, and various forms of conjugates that serve as more efficient drug carrier systems. Its ability to form complexes with different types of drugs through ionic interactions, hydrogen bonds, and van der Waals interactions provides flexibility in designing target-specific drug carrier systems (Danish et al., 2017; Heck et al., 2024; Khalid Danish et al., 2022).

In recent developments, chitosan derivatives have opened new opportunities to expand applications and reduce toxicity. Chemical modifications such as *thiolation*, methylation, and functionalization with various active groups have produced chitosan derivatives with more specific properties. One interesting example is *6-mercaptonicotinamide*-functionalized chitosan, which shows potential as an excipient for mucoadhesive drug carrier systems with increased biodegradability. This derivatization not only enhances the effectiveness of chitosan as an excipient but also broadens its spectrum of applications in drug delivery systems (Hemmingsen et al., 2021).

The sterilization and pharmacokinetic aspects of chitosan are also important considerations in pharmaceutical applications. While its use as a pharmaceutical excipient in the ocular field is well established, several aspects related to ocular administration—such as sterilization and excipient pharmacokinetics—still require further research. Chitosan's compatibility with various pharmaceutical sterilization methods and its biological stability after sterilization are crucial factors in the practical implementation of chitosan as an excipient. Given the enormous potential of chitosan in this role, a comprehensive systematic study is needed to compile and analyze the various studies that have been conducted. A systematic literature review is the appropriate method for evaluating the available scientific evidence regarding the use of chitosan as an excipient in pharmaceutical formulations. Through a structured and systematic approach, it is possible to obtain a deeper understanding of the latest developments, advantages, limitations, and future prospects of chitosan as a pharmaceutical excipient.

Based on the background described above, the formulation of the research problem in this study is as follows: How has research on the use of chitosan as an excipient in the formulation of pharmaceutical preparations developed based on a systematic review of the scientific literature? What is the mechanism of action of chitosan as an excipient in various forms of pharmaceutical preparations, and how is it applied in drug delivery systems? What are the advantages and limitations of chitosan as a pharmaceutical excipient compared to conventional excipients? This study aims to systematically review and analyze various scientific publications regarding the use of chitosan as an excipient in the formulation of pharmaceutical preparations. Specifically, it aims to identify recent developments in the application of chitosan as a pharmaceutical excipient, evaluate its mechanism of action in various forms of drug preparations, and analyze its advantages and limitations as an excipient in drug delivery

systems. The study also aims to identify existing research gaps and provide recommendations for the further development of chitosan as a potential pharmaceutical excipient.

This research is expected to benefit various parties in the pharmaceutical industry. For researchers and academics, it can serve as a comprehensive reference on the latest developments of chitosan as a pharmaceutical excipient and provide a foundation for further studies. For the pharmaceutical industry, the results can offer strategic information regarding the potential of chitosan as a more sustainable and biocompatible alternative to conventional excipients. For pharmaceutical and formulation practitioners, this research can serve as a guide in selecting and applying chitosan as an excipient in the development of innovative and effective pharmaceutical preparations.

RESEARCH METHOD

Research Design

This study is a systematic literature review (*SLR*) that uses a qualitative approach to analyze and synthesize scientific evidence regarding the use of chitosan as an excipient in the formulation of pharmaceutical preparations. The research was conducted following the guidelines of PRISMA 2020 (*Preferred Reporting Items for Systematic Reviews and Meta-Analyses*) to ensure transparency and reproducibility in the systematic review process. The methodology employed includes the stages of identification, screening, eligibility, and inclusion of articles based on predetermined criteria.

Inclusion and Exclusion Criteria

The inclusion criteria for this study comprise research articles published in peer-reviewed journals between 2021 and 2025, written in English, and discussing the application of chitosan as an excipient in pharmaceutical formulations. Eligible articles must present a clear methodology, report results relevant to the research topic, and be accessible in full text. Furthermore, studies should address specific pharmaceutical aspects of chitosan rather than general biomedical applications.

Exclusion criteria include unsystematic review articles, opinion pieces, editorials, conference proceedings, theses, and articles not available in English. Studies addressing chitosan in non-pharmaceutical applications—such as food processing, textiles, or other industrial uses—are also excluded. In addition, research conducted before 2021 and articles without an abstract or full-text access are excluded from the analysis.

Search Strategy

A comprehensive literature search was conducted using electronic databases, including PubMed, ScienceDirect, Scopus, and Web of Science. Keywords used in the search consisted of combinations of “chitosan”, “excipient”, “pharmaceutical”, “drug delivery”, “formulation”, “tablet”, “capsule”, “oral”, “topical”, “controlled release”, and “bioavailability”. Boolean operators (*AND*, *OR*, *NOT*) were applied to refine the search for more specific and relevant results. The search strategy was adapted to suit the characteristics of each database to maximize both sensitivity and specificity. The search process was carried out between January and March 2025 to ensure the inclusion of the most recent studies.

Article Selection and Data Extraction

Article selection was performed in two main stages: title and abstract screening, followed by full-text review. In the first stage, titles and abstracts were screened to identify potentially relevant studies based on the established inclusion criteria (Mengist et al., 2020). Disagreements between reviewers were resolved through discussion and consensus or, when necessary, by involving a third reviewer. In the second stage, articles that passed the initial screening were assessed in full text to determine their eligibility for inclusion in the systematic review.

Data extraction was conducted systematically, gathering information on study characteristics, methodology, the type of chitosan application, dosage forms, main findings, and conclusions. Quality assessment was performed using criteria appropriate to the study design to ensure the reliability and validity of the analyzed articles.

Data Analysis and Synthesis

Data analysis was conducted narratively by grouping studies according to the type of chitosan application as an excipient, the pharmaceutical dosage form, and the mechanism of action. Data synthesis involved identifying patterns, trends, and gaps in existing research. A thematic analysis approach was used to categorize findings based on the pharmacological, pharmacokinetic, and pharmacodynamic aspects of chitosan as an excipient. The quality of evidence was evaluated according to study design, sample size, methodology, and the consistency of results across studies (van Dinter et al., 2021). Heterogeneity among studies was analyzed to identify factors contributing to variability in results. The analysis aimed to define the advantages and limitations of chitosan as an excipient, as well as its potential for future development.

The results of the analysis are presented in tables, diagrams, and descriptive narratives to provide a comprehensive overview of the use of chitosan in pharmaceutical formulations based on the latest evidence.

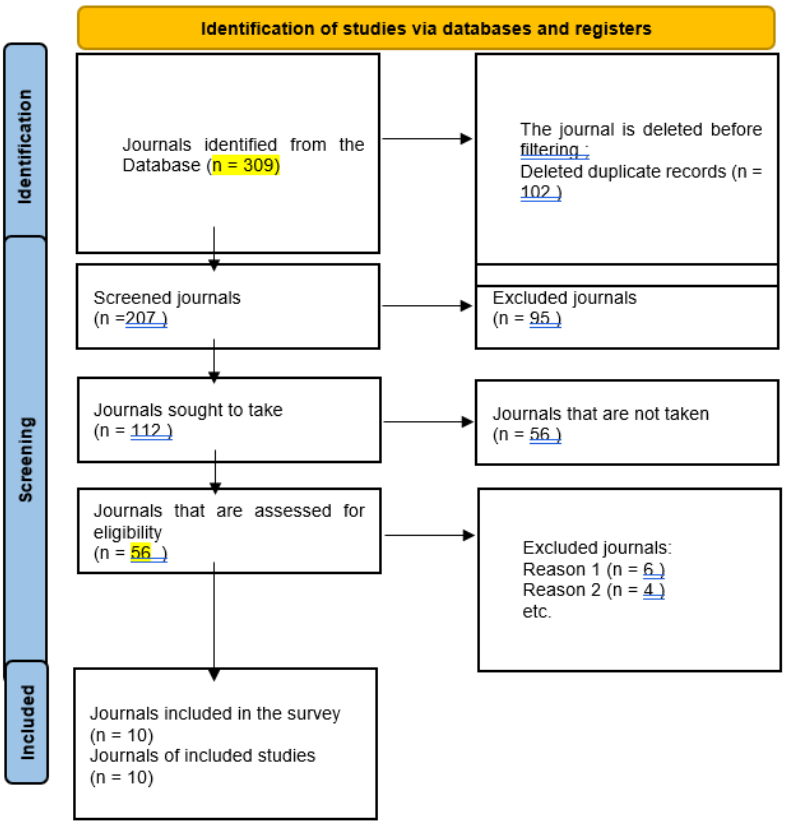

Figure 1. Flowchart Prisma

Based on the *PRISMA* diagram presented, this study initially identified 309 journals from the database search. After the duplication check, 102 journals were removed as duplicates, leaving 207 journals for the next stage. At the screening stage, of the 207 journals screened, 95

were excluded, leaving 112 journals for further review. Subsequently, 56 journals that did not meet the inclusion criteria were excluded, leaving 56 journals for the eligibility assessment.

During the eligibility assessment, further elimination was carried out based on two specific criteria. The first criterion resulted in the exclusion of 6 journals, while the second criterion excluded 4 journals, for a total of 10 journals excluded at this stage. The final result was 10 journals included in the review.

RESULT AND DISCUSSION

Table 1. Synthesis of Systematic Literature Review

	Author	Heading	Method	Sample	Researchers' Findings	Relevance to the Topic
1	(Mazayen et al., 2022)	Pharmaceutical nanotechnology: from the bench to the market	Literature Review	Different types of nanosystems including carbon nanotubes, paramagnetic nanoparticles, dendrimers, nanoemulsions	Nanoparticles as a drug delivery system provide advantages such as increased efficacy and reduction of drug side effects. The physicochemical properties of the initial material and the method of preparation affect the shape and characteristics of the nanoparticles	Relevant because chitosan can be used as a raw material to form nanoparticles in drug delivery systems
2	(Samir et al., 2022)	Recent advances in biodegradable polymers for sustainable applications	Literature Review	Biodegradable polymers produced through the treatment of chemicals, microorganisms, and enzymes	Biodegradable polymers have several issues in practical applications. The research discusses the treatment, composite, blending, and modeling of biodegradable polymers	It is very relevant because chitosan is an environmentally friendly biodegradable polymer and can be used as an excipient
3	(Lawrencia et al., 2021)	Controlled Release Fertilizers: A Review on	Literature Review	Controlled release fertilizers (CRFs) with	Natural polymers can be used as coating	Relevant because the principle of coating with

	Author	Heading	Method	Sample	Researchers' Findings	Relevance to the Topic
		Coating Materials and Mechanism of Release		synthetic and natural polymer coating materials	materials for CRFs. Factors that affect the rate of release include the physical and chemical properties of the polymer	natural polymers such as chitosan can be applied in pharmaceutical formulations for controlled release
4	(Algahtani et al., 2021)	3D Printing of Dapagliflozin Containing Self-Nanoemulsifying Tablets: Formulation Design and In Vitro Characterization	Experimental Study	The self-nanoemulsifying tablet contains dapagliflozin made by 3D printing semisolid pressure-assisted microsyringe (PAM)	The formulation produces nanoemulsions with a droplet size of 104.7 ± 3.36 nm and a polydispersion of 0.063 ± 0.024. The tablet shows an immediate-release profile of >75% in 20 minutes	Relevant because the 3D printing technique can be used for tablet formulations with chitosan as an excipient
5	(Yermak et al., 2022)	Mucoadhesive Marine Polysaccharides	Literature Review	Maritime polysaccharides such as chitosan, carrageenan, and alginate as mucoadhesive polymers	Mucoadhesive polymers with charged groups or nonionic groups can form hydrogen bonds and electrostatic interactions with mucosal surfaces. Maritime biopolymer carbohydrates show good biocompatibility and biodegradability	It is very relevant because chitosan as a maritime polysaccharide has mucoadhesive properties that can be used in drug delivery systems
6	(Chiong et al., 2021)	Integrating Emerging Polymer Chemistries for the Advancement	Literature Review	Recyclable, biodegradable and biocompatible polymers for	The development of polymers with recyclable, biodegradable,	Relevant because it shows the trend of using biodegradable polymers such

	Author	Heading	Method	Sample	Researchers' Findings	Relevance to the Topic
		of Recyclable, Biodegradable, and Biocompatible Electronics		electronic applications	and biocompatible properties is important for environmentally and human-friendly electronics applications	as chitosan in various technological applications
7	(Patil et al., 2021)	Chitosan based co-processed excipient for improved tableting	Experimental Study	The 3-component excipient system consists of chitosan, mannitol, and crospovidone developed using spray drying techniques	Coprocessed excipient shows significant increased density and flowability. The combination of 50% chitosan, 43% mannitol, and 6.5% crospovidone results in a tablet with a hardness of 100 N and a disintegration time of <25 seconds	It is very relevant because it directly discusses chitosan as an excipient in tablet formulation and shows how to overcome the limitations of chitosan
8	(Cui et al., 2021)	Opportunities and challenges of three-dimensional printing technology in pharmaceutical formulation development	Literature Review	3D printing technology for pharmaceutical formulation development	3D printing technology has advantages in the complexity of product design, personalization, and on-demand manufacturing. Providing innovative strategies to develop novel drug delivery systems	Relevant because 3D printing technology can be used for the formulation of pharmaceutical preparations that use chitosan as an excipient
9	(Zillen et al., 2021)	Natural and bioinspired excipients for dry powder	Literature Review	Natural and bio-inspired excipient for dry inhalation powder	Natural excipient can improve powder dispercibility,	Relevant because chitosan as a natural biodegradable

	Author	Heading	Method	Sample	Researchers' Findings	Relevance to the Topic
		inhalation formulations		formulations including amino acids, sugars, lipids, and biodegradable polymers	provide protection against moisture, and facilitate continuous release. Biodegradable polymers are used for sustained release and targeted drug delivery	polymer can be used in inhalation powder formulations
10	(Sultana et al., 2022)	Nano-based drug delivery systems: Conventional drug delivery routes, recent developments and future prospects	Literature Review	System nanocarrier include solid nanoparticles, liposome, dendrimers, polymeric nanoparticles, polymeric micelles, virus-like nanoparticles, carbon nanotube, dan mesoporous silica nanoparticles	Nanocarriers can overcome the limitations of conventional methods such as instability, uncontrolled release, and side effects. Innovative delivery system can increase the effectiveness of therapy	Relevant because chitosan can be used as a raw material to make polymeric nanoparticles in drug delivery systems

Source: processed data

Based on a comprehensive analysis of the 10 articles studied, several hypotheses can be formulated that are the basis for further research:

1) Hypothesis 1: Chitosan as an excipient can increase drug bioavailability through its mucoadhesive and permeation enhancer properties, especially in oral and topical drug delivery systems.
2) Hypothesis 2: Co-processed excipient formulations that combine chitosan with other excipients will produce better pharmacotechnical properties than the use of chitosan as a single excipient.
3) Hypothesis 3: Nanoformulation technology with chitosan as a carrier will provide more effective controlled release and reduce drug side effects compared to conventional systems.
4) Hypothesis 4: The integration of chitosan in 3D printing technology will allow the development of personalized medicine with formulations tailored to the individual needs of patients.
5) Hypothesis 5: The biodegradable and biocompatible properties of chitosan will be a competitive advantage in the era of pharmaceutical green chemistry and sustainable drug development.

Based on the article selection process that follows the PRISMA 2020 guidelines, 10 articles were obtained that met the inclusion criteria for the analysis of this systematic literature review. The characteristics of the articles analyzed showed a balanced distribution between experimental studies (20%) and literature reviews (80%), with the majority of publications coming from 2021-2022. Geographic analysis shows that research on chitosan as an excipient is spread across countries, with a primary focus on applications in drug delivery systems and innovative pharmaceutical formulations.

Table 2. Distribution of Article Characteristics by Study Type and Year of Publication

Year	Literature Review	Experimental Study	Total
2021	5	1	6
2022	3	1	4
Total	8	2	10

Source: processed data

The analysis shows that chitosan has a significant role in the development of nanoformulation systems for drug delivery. Research by Mazazen et al. (2022) identified that nanoparticles as a drug delivery system provide advantages such as increased efficacy and reduction of drug side effects, where the physicochemical properties of the initial ingredients and preparation methods affect the shape and characteristics of nanoparticles. These findings are reinforced by Sultana et al. (2022) who show that nanocarriers can overcome the limitations of conventional methods such as instability, uncontrolled release, and side effects, where chitosan can be used as a raw material to make polymeric nanoparticles in drug delivery systems. An experimental study conducted by Patil et al. (2021) provides strong empirical evidence regarding the utilization of chitosan in tablet formulations. This study developed a three-component co-processed excipient system consisting of chitosan, mannitol, and crospovidone using the spray drying technique. The results showed that the combination of 50% chitosan, 43% mannitol, and 6.5% crospovidone resulted in tablets with a hardness of 100 N and a disintegration time of less than 25 seconds. These findings suggest that chitosan can overcome limitations as a single excipient through co-processed excipient formulations.

The research of Yermak et al. (2022) provides an in-depth perspective on the mucoadhesive properties of chitosan as a maritime polysaccharide. The study shows that mucoadhesive polymers with charged groups or nonionic groups can form hydrogen bonds and electrostatic interactions with mucosal surfaces. Maritime biopolymer carbohydrates, including chitosan, exhibit good biocompatibility and biodegradability, making them ideal candidates for mucoadhesive drug delivery systems. A comprehensive analysis conducted by Samir et al. (2022) shows that biodegradable polymers, including chitosan, have several issues in practical applications that need to be addressed through treatment, composite, blending, and modeling of biodegradable polymers. These findings are in line with research by Chiong et al. (2021) which shows that the development of polymers with recyclable, biodegradable, and biocompatible properties is important for environmentally and human-friendly applications. The study Lawrencia et al. (2021) provides important insights into the controlled release mechanism using natural polymers as a coating material. This study shows that factors affecting the release rate include the physical and chemical properties of the polymer, which can be applied in pharmaceutical formulations for controlled release using chitosan.

Research by Algahtani et al. (2021) and Cui et al. (2021) shows the potential of 3D printing technology in the formulation of pharmaceutical preparations using chitosan as an excipient. Algahtani et al. (2021) successfully developed a formulation of self-nanoemulsifying tablets containing dapagliflozin with 3D printing techniques, producing nanoemulsions with a droplet size of 104.7 ± 3.36 nm and an immediate-release profile of >75% in 20 minutes. Meanwhile, Cui et al. (2021) identified that 3D printing technology provides advantages in the complexity

of product design, personalization, and on-demand manufacturing. Zillen et al. (2021) explored the use of natural and bio-inspired excipient for dry inhaled powder formulations, where chitosan as a biodegradable polymer can improve powder dispersibility, provide moisture protection, and facilitate sustained release for sustained release and targeted drug delivery.

Table 3. Distribution of Chitosan Application Based on Dosage Form

Preparation Form	Number of Studies	Percentage
Nanoformulation	3	30%
Tablet	3	30%
Mucoadhesive System	2	20%
Inhalation Powder	1	10%
Controlled Release	1	10%

Source: processed data

The results of this systematic literature review analysis show that chitosan has great potential as an excipient in the formulation of modern pharmaceutical preparations. Chitosan's main advantage lies in its biodegradable, biocompatible, and mucoadhesive properties that provide flexibility in a wide range of pharmaceutical applications. The integration of chitosan in innovative technologies such as nanoformulation and 3D printing demonstrates the adaptability of this polymer to the development of contemporary pharmaceutical technology. However, challenges in standardization and regulation are still factors that need to be considered for the practical implementation of chitosan as an excipient in the pharmaceutical industry.

CONCLUSION

This systematic literature review demonstrates that chitosan holds very promising potential as an excipient in modern pharmaceutical formulations. Based on the analysis of 10 articles that met the inclusion criteria, it was found that chitosan offers significant advantages across a wide range of pharmaceutical applications, from nanoformulation systems to conventional tablet formulations. The primary advantages of chitosan lie in its biodegradable, biocompatible, and mucoadhesive properties, which provide exceptional flexibility in the development of innovative drug delivery systems. Its mucoadhesive nature makes it particularly suitable for drug delivery systems requiring interaction with the mucosa, such as oral, nasal, and ocular applications. Moreover, its ability to form nanoparticles, microspheres, and hydrogels presents substantial opportunities for developing more effective controlled-release systems. *Co-processed excipient* technology, which combines chitosan with other excipients, has been shown to overcome the limitations of chitosan as a single excipient, thereby improving the pharmacotechnical properties of tablet formulations.

The integration of chitosan into innovative technologies such as *3D printing* and nanoformulations further demonstrates the adaptability of this polymer to contemporary pharmaceutical advancements. Its use in inhalation powder formulations also shows promising potential for respiratory drug delivery applications. However, challenges regarding standardization, regulation, and quality control remain important considerations for the practical implementation of chitosan as an excipient in large-scale pharmaceutical manufacturing. This review identifies that chitosan has bright prospects in the era of pharmaceutical *green chemistry* and sustainable drug development, aligning with global trends toward the use of environmentally friendly natural ingredients in the pharmaceutical industry. Nonetheless, further research is required to optimize its application in various dosage forms and to develop adequate regulatory standards that will facilitate the safe and effective implementation of chitosan as a pharmaceutical excipient.

REFERENCES

Abidin, I. Z., Murphy, E. J., Fehrenbach, G. W., Gately, N., & Major, I. (2024). Chitosan-(poly)acrylic acid polyelectrolyte complexes: Enhanced mucoadhesion and sustained drug release in vaginal tablets. *Carbohydrate Polymer Technologies and Applications*, *7*. https://doi.org/10.1016/j.carpta.2024.100480

Algahtani, M. S., Mohammed, A. A., Ahmad, J., Abdullah, M. M., & Saleh, E. (2021). 3d printing of dapagliflozin containing self-nanoemulsifying tablets: Formulation design and in vitro characterization. *Pharmaceutics*, *13*(7). https://doi.org/10.3390/pharmaceutics13070993

Chiong, J. A., Tran, H., Lin, Y., Zheng, Y., & Bao, Z. (2021). Integrating Emerging Polymer Chemistries for the Advancement of Recyclable, Biodegradable, and Biocompatible Electronics. *Advanced Science*, *8*(14), 1–30. https://doi.org/10.1002/advs.202101233

Cui, M., Pan, H., Su, Y., Fang, D., Qiao, S., Ding, P., & Pan, W. (2021). Opportunities and challenges of three-dimensional printing technology in pharmaceutical formulation development. *Acta Pharmaceutica Sinica B*, *11*(8), 2488–2504. https://doi.org/10.1016/j.apsb.2021.03.015

Danish, M. K., Vozza, G., Byrne, H. J., Frias, J. M., & Ryan, S. M. (2017). Formulation, Characterization and Stability Assessment of a Food-Derived Tripeptide, Leucine-Lysine-Proline Loaded Chitosan Nanoparticles. *Journal of Food Science*, *82*(9). https://doi.org/10.1111/1750-3841.13824

Heck, K., Farris, E., & Pannier, A. K. (2024). Formulation of Chitosan–Zein Nano-in-Microparticles for Oral DNA Delivery. In *Methods in Molecular Biology* (Vol. 2720). https://doi.org/10.1007/978-1-0716-3469-1_12

Hemmingsen, L. M., Škalko-Basnet, N., & Jøraholmen, M. W. (2021). The expanded role of chitosan in localized antimicrobial therapy. In *Marine Drugs* (Vol. 19, Issue 12). https://doi.org/10.3390/md19120697

Khalid Danish, M., Gleeson, J. P., Brayden, D. J., Byrne, H. J., Frías, J. M., & Ryan, S. M. (2022). Formulation, Characterisation and Evaluation of the Antihypertensive Peptides, Isoleucine-Proline-Proline and Leucine-Lysine-Proline in Chitosan Nanoparticles Coated with Zein for Oral Drug Delivery. *International Journal of Molecular Sciences*, *23*(19). https://doi.org/10.3390/ijms231911160

Lawrencia, D., Wong, S. K., Low, D. Y. S., Goh, B. H., Goh, J. K., Ruktanonchai, U. R., Soottitantawat, A., Lee, L. H., & Tang, S. Y. (2021). Controlled release fertilizers: A review on coating materials and mechanism of release. *Plants*, *10*(2), 1–26. https://doi.org/10.3390/plants10020238

Mazayen, Z. M., Ghoneim, A. M., Elbatanony, R. S., Basalious, E. B., & Bendas, E. R. (2022). Pharmaceutical nanotechnology: from the bench to the market. *Future Journal of Pharmaceutical Sciences*, *8*(1). https://doi.org/10.1186/s43094-022-00400-0

Mengist, W., Soromessa, T., & Legese, G. (2020). Method for conducting systematic literature review and meta-analysis for environmental science research. *MethodX*, *7*, 2–10.

Patil, S., Pandit, A., Godbole, A., Dandekar, P., & Jain, R. (2021). Chitosan based co-processed excipient for improved tableting. *Carbohydrate Polymer Technologies and Applications*, *2*(January), 100071. https://doi.org/10.1016/j.carpta.2021.100071

Ramadhan, L. O. A. N., Agusu, L., Kadir, L. A., Saputra, R., & Nurdin, F. (2020). Preparation Polyelectrolyte Complexes of Chitosan-Polyacrylic Acid-Modified Iron Sand Leachate for Proton Exchange Membranes. *Polymer-Plastics Technology and Materials*, *59*(12). https://doi.org/10.1080/25740881.2020.1738468

Samir, A., Ashour, F. H., Hakim, A. A. A., & Bassyouni, M. (2022). Recent advances in biodegradable polymers for sustainable applications. *Npj Materials Degradation*, *6*(1). https://doi.org/10.1038/s41529-022-00277-7

Sultana, A., Zare, M., Thomas, V., Kumar, T. S. S., & Ramakrishna, S. (2022). Nano-based drug delivery systems: Conventional drug delivery routes, recent developments and future prospects. *Medicine in Drug Discovery*, *15*(May), 100134. https://doi.org/10.1016/j.medidd.2022.100134

Varshosaz, J., Tavakoli, N., Moghaddam, F., & Ghassami, E. (2015). Polyelectrolyte complexes of chitosan for production of sustained release tablets of bupropion HCl. *Farmacia*, *63*(1).

Yermak, I. M., Davydova, V. N., & Volod'ko, A. V. (2022). Mucoadhesive Marine Polysaccharides. *Marine Drugs*, *20*(8). https://doi.org/10.3390/md20080522

You, J., Xie, S., Cao, J., Ge, H., Xu, M., Zhang, L., & Zhou, J. (2016). Quaternized Chitosan/Poly(acrylic acid) Polyelectrolyte Complex Hydrogels with Tough, Self-Recovery, and Tunable Mechanical Properties. *Macromolecules*, *49*(3). https://doi.org/10.1021/acs.macromol.5b02231

Zillen, D., Beugeling, M., Hinrichs, W. L. J., Frijlink, H. W., & Grasmeijer, F. (2021). Natural and bioinspired excipients for dry powder inhalation formulations. *Current Opinion in Colloid and Interface Science*, *56*, 101497. https://doi.org/10.1016/j.cocis.2021.101497