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Review

Chitosan and PVP: Versatile Biopolymers for Drug Delivery and Advanced Materials

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ABSTRACT

Chitosan (CS) is one of the most studied natural polymers in biomaterials because its extraction from the exoskeletons of crustaceans such as shrimp and crabs is not too complex or expensive. Additionally, this polysaccharide has hydroxyl and primary amino functional groups in its structure, making it particularly useful for interacting with other compounds, mainly in acidic media. Polyvinylpyrrolidone (PVP), like chitosan, has antibacterial properties and biocompatibility with living tissue, which has made these two biopolymers the object of study for the development of new materials with desired properties and in the design of drug delivery systems (DDS). Both materials can form films and gels; however, one advantage of PVP compared to CS is its solubility in water. Another essential feature of these biopolymers is their ability to form complexes with synthetic drugs and natural products, which makes them especially useful in the design of DDS. This review presents the main characteristics of these biopolymers and addresses the possibility of combining them to develop materials and DDS that provide individual characteristics to improve their physical, chemical, and biological properties.

Keywords: chitosan (CS), polyvinylpyrrolidone (PVP), drug delivery systems (DDS), biomaterials.

INTRODUCTION

Modern materials that can offer better absorption and antimicrobial properties for faster wound healing have helped to replace conventional wound dressing materials like cotton wool, lint, and gauze [1]. Drug delivery systems (DDS), which include liposomes, microspheres, nanoparticles, gels, prodrugs, and many others, are used to increase the therapeutic effects of a pharmaceutical drug or a natural compound in a specific diseased site while minimizing toxicological effects [2]. Compared to synthetic ones, biopolymers used in DDS ensure biocompatibility, biodegradability, and low immunogenicity. Silk fibroins, collagen, gelatin, albumin, starch, cellulose, and chitosan are just a few examples of biopolymers that can be easily made into suspensions that act as carriers for both large and small drug molecules [3].

Specific polymers with a range of molecular weights, such as polyvinylpyrrolidone (PVP), chitosan (CS), poly(ethylene glycol)/poly(ethylene oxide), and other oligomer/polymers with a similar molecular formula, can present various applications in drug delivery through scientific integration depending on the application of nanotechnologies [4]. Developing secure, non-toxic, and accessible DDS based on natural molecules such as peptides, polysaccharides, and proteins is considerably aided by the immense diversity of structures and functional groups accessible for chemical modification [5]. For packaging in biomedical and pharmaceutical applications, novel approaches utilizing biopolymer-based materials with various constituents seem especially appealing [6].

Biodegradable polymeric materials have come a long way in terms of development for biomedical applications [7]. Therapeutic devices, such as transient implants and three-dimensional scaffolds for tissue engineering, are often made of biodegradable polymeric materials [8]. The scientific community is currently interested in the mucosal route for noninvasive drug delivery via the oral, nasal, pulmonary, or vaginal routes [9]. Chitosan is a linear polysaccharide with notable physicochemical and biological characteristics, including biodegradability, biocompatibility, nonimmunogenicity, non-toxicity, bioadhesion, antifungal, antibacterial, and hemostatic action [10]. This is because chitosan, a biopolymer considered authorized for wound patches and safe for human consumption applications, has gained attention [11]. Chitosan has been studied for various pharmacological properties, and its use in tissue engineering and regenerative medicine is well-known [12].

On the other hand, promising DDS for treating serious illnesses like cancer, infections, and neurodegenerative disorders can be found among polymeric nanoparticles loaded with medications [13]. Polyvinylpyrrolidone (PVP) is an inert, non-toxic, pH-stable, temperature-resistant, biocompatible, and biodegradable polymer that aids in the packaging and delivering hydrophilic and lipophilic medications [14]. These benefits make PVP a flexible excipient that can be used in developing various controlled delivery systems, from the most basic to the most cutting-edge [15]. At the moment, several PVP-based systems have been created to deliver multiple active principles derived from both natural and synthetic sources [16]. Also, PVP has been used in various formulations and morphologies, including nanoparticles and microparticles, hydrogels, films, tablets, and fibers. PVP is one of the most suitable and promising polymers for creating novel pharmaceutical forms due to its adaptability and unique properties [17]. PVP has also been used to develop DDS, and studies have shown that it has effective antibacterial properties against *S. aureus*, *E. coli*, *P. aeruginosa*, and *Bacillus subtilis*, as well as effective fungicidal properties against a variety of yeasts and molds [18].

THEMATIC DEVELOPMENT

General chemical and biological properties of chitosan (CS)

Chitosan (Figure 1) is considered a polysaccharide that is formed from chitin, and the partial deacetylation of D-glucosamines and N-acetyl-D-glucosamines 19 produces this. At the same time, it has a wide variety of biological properties [19]. Chitosan has beneficial properties such as biocompatibility, low toxicity, and biodegradability and finds applications in various industries [20]. It is used in the pharmaceutical sector as a supplement that acts as a fat blocker and helps lower cholesterol levels by removing fats and cholesterol from the body rather than allowing the body to absorb them [21]. Besides, it is used in the cosmetics industry, where it is

included in various skin care products, such as face creams, among others, and in the medical field, it is incorporated into preparations for tissue regeneration and wound healing [22,23].

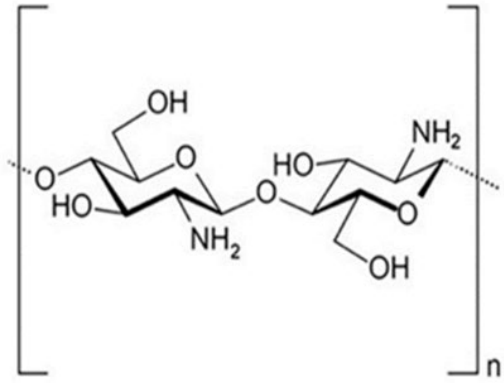


Figure 1. Chitosan chemical structure.

On the other hand, chitin must reach approximately 50% of the deacetylation degree to form chitosan, at which point it becomes soluble in acidic aqueous environments [24]. This process occurs through the protonation of the -NH2 group at the C-2 position, transforming it from a polysaccharide into a polyelectrolyte under acidic conditions. Nevertheless, due to its solubility in aqueous solutions, it is used in various forms, such as gels and fibers [25]. As depicted in Figure 2, chitosan exhibits functional groups and primary amino and hydroxyl groups (primary and secondary), giving it its particular characteristics. Furthermore, the acetamide group and glycosidic bonds provide some modifications that result in polymers with novel properties and are considered functional groups [26,27].

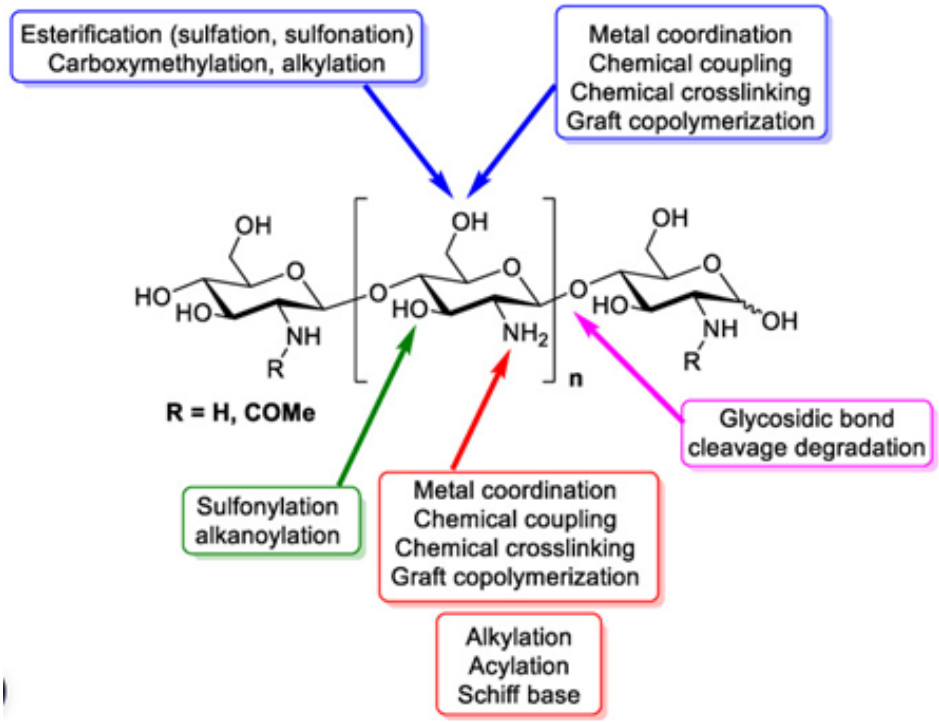


Figure 2. Functional groups of chitosan (-OH, -NH₂, and glycosidic bond) and its chemical reactivities.

Chitosan displays a semicrystalline configuration when in a solid state. Its physical structure has undergone comprehensive scrutiny, resulting in various distinct forms as documented in the literature [28,29]. To produce individual chitosan crystals, scientists employed chitin that had been fully deacetylated and possessed a low molecular weight [30]. The electron diffraction pattern aligns precisely with an orthorhombic unit cell ($P2_12_12_1$), featuring dimensions of a = 0.807 nm, b = 0.844 nm, and c = 1.034 nm [31,32]. This unit cell encompasses two chitosan chains oriented antiparallelly with water molecules. Additionally, prior studies have shown how experimental conditions affect their crystalline nature [33,34].

Various chitosan derivatives have been developed to enhance characteristics, such as solubility or biodegradability, and introduce new functionalities or properties [35]. For instance, solubility in aqueous media has been enhanced through deacetylation, depolymerization, or quaternization, among others [36]. Modifications to chitosan have resulted in new activities; for example, 6-O-sulfated chitosan has been shown to promote neuronal differentiation, while phosphorylated chitosan has demonstrated corrosion inhibition properties [37,38].

The primary studies on chitosan revolve around its production with different molecular weights and deacetylation degrees (DA) starting from chitin. Additionally, there is a focus on their benefits, the creation of derivatives, and their practical uses. Sponges, powders, and fibers can be produced by chitosan or from solutions [39]. Chitosan, known for its affordability, lack of toxicity, and the presence of reactive amino groups, has demonstrated its utility across domains [40]. It serves as an antimicrobial agent in agriculture, a potential stimulant for plant defense mechanisms, a clarifying agent in wastewater treatment, an additive in the food industry, a moisturizing component in cosmetics, and, more recently, a pharmaceutical agent in biomedicine [41]. Over the past few years, significant focus has been directed towards examining the antimicrobial efficacy of chitosan, and its modified forms against various categories of microorganisms, including bacteria and fungi [42] Chitin and chitosan possess a wide range of biological activities, including antitumoral, antimicrobial, antioxidant, and anti-inflammatory properties, making them potentially valuable as therapeutic polymers [43]. It is noteworthy that, as of now, regulatory agencies have only recognized chitosan and chitosan hydrochloride as excipients rather than standalone drugs for disease treatment [44].

The emergence of bacterial antibiotic resistance is a pressing public health issue that brings to light the need for effective alternatives against this problem [45]. Chitosan, its derivatives, and chitooligosaccharides demonstrate antimicrobial effectiveness against various microorganisms, including bacteria, filamentous fungi, and yeast [46]. Notably, chitosan appears to possess growth-inhibiting properties, as bacteria can resume growth once the polymer is removed from the medium. This is significant, as resistant populations may arise if these bacteria adapt to chitosan [47].

Liberation of drugs from particulate systems based on chitosan relies on factors such as the degree of cross-linking, the structure, dimensions, and compactness of the system, as well as the physical and chemical characteristics of the drug; additionally, the inclusion of adjuvants plays a role [48]. *In vitro* release is also influenced by factors like enzymes in the dissolution medium, pH, and polarity. Figure 3 shows the drug release process from chitosan particulate systems encompassing three distinct mechanisms [49].

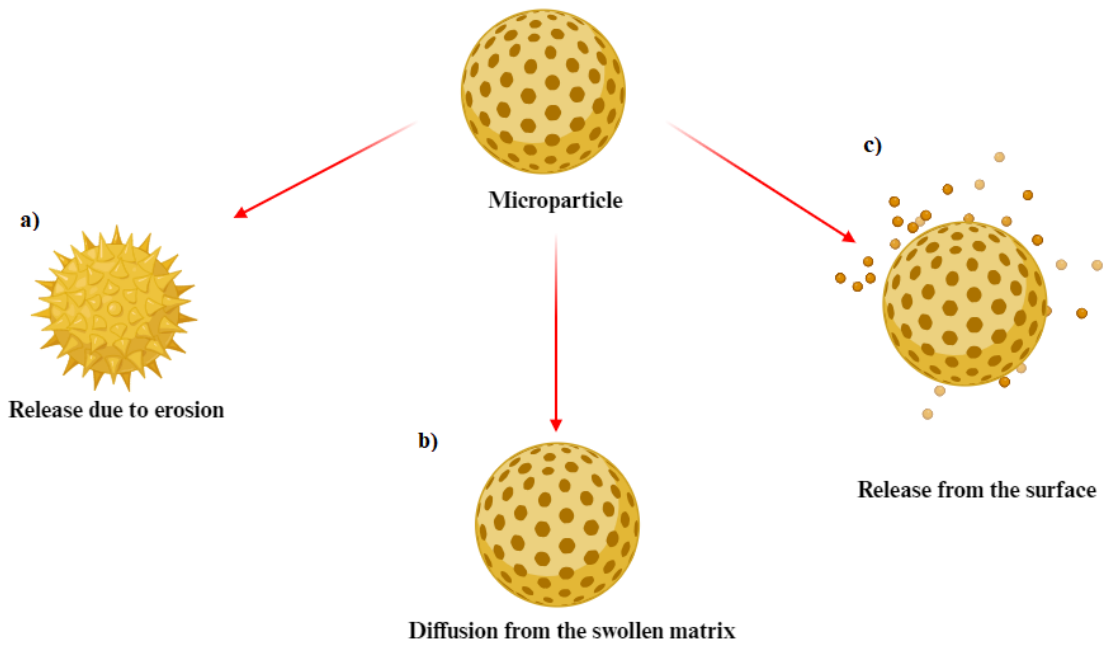


Figure 3. The drug release process from chitosan particulate systems encompasses three distinct mechanisms: a) liberation due to polymer erosion, b) diffusion through the expanded matrix, and c) discharge from the particle surface.

Generally, drug release does not involve a single type of mechanism. For example, when surface release occurs, the adsorbed drug dissolves instantly upon contact with the release medium. Drugs trapped in the surface layer of particles also follow this mechanism. This form of drug release is known as the burst effect [47]. In swelling-controlled release systems, the drug is dispersed within a rigid polymer. The polymer undergoes swelling when it encounters biological fluids, but there is no through the polymer phase. As the penetrant enters the rigid polymer, the polymer's glass transition temperature decreases due to the relaxation of the polymer chains. This allows the drug to diffuse out of the swollen, flexible polymer. This type of system is characterized by two dynamic boundaries: the boundary separating the flexible, swollen part from the rigid, glassy region (which advances with a certain speed) and the interface between the polymer and the fluid. The rate at which the drug is released is governed by the speed and position of the boundary [50]. Figure 4 shows the different drug delivery systems using chitosan-based nanoparticles.

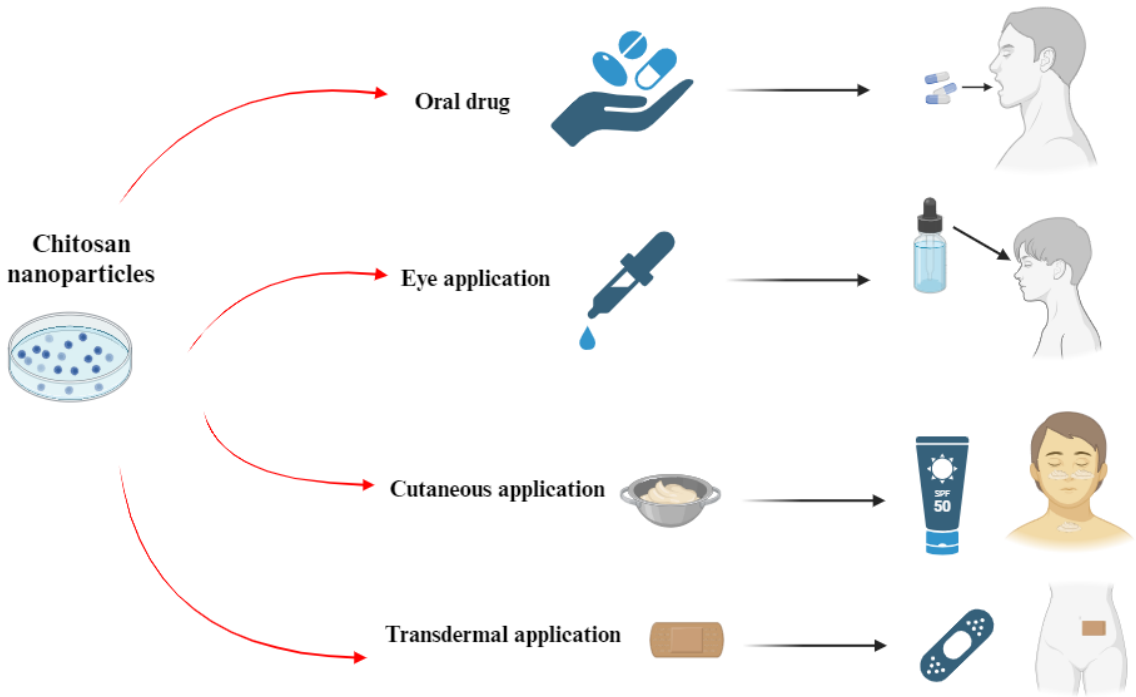


Figure 4. Chitosan-based nanoparticles are used as effective drug delivery systems (DDS), such as oral drugs, eye drops, and skin and transdermal applications.

General chemical and biological properties of Polyvinylpyrrolidone (PVP)

The synthetic polyvinylpyrrolidone (PVP), often known as polyvidone or povidone, is created by polymerizing N-vinylpyrrolidone monomer [51]. PVP is a hydrophilic polymer commonly used in drug delivery systems [52]. It is highly soluble in polar organic solvents. As the molecular weight of PVP increases, its solubility may slightly decrease [53]. As depicted in Figure 5, the functional groups present in polyvinylpyrrolidone (PVP) are highlighted. PVP exhibits solubility in water, alcohols, ammonia, and halogenated hydrocarbons.

Conversely, PVP demonstrates insolubility in ethers, hydrocarbons, and particular ketones [54]. PVP has different biological and physicochemical properties (Figure 6). Polyvinylpyrrolidone (PVP) has the potential to improve hydrophilicity significantly on the surface of some compatible materials; Zhao et al. [55] demonstrated that PVP-treated samples, which maintained a specific contact angle, showed higher hydrophilicity compared to samples that were not subjected to PVP treatment. The hydrophilic nature of PVP improves pure water flow contact angle and has more excellent resistance to scale formation [56]. PVP can prevent drug degradation and improve the stability of some others [57]. Moreover, amorphous solid dispersions enhance drug dissolution rates and bioavailability [58].

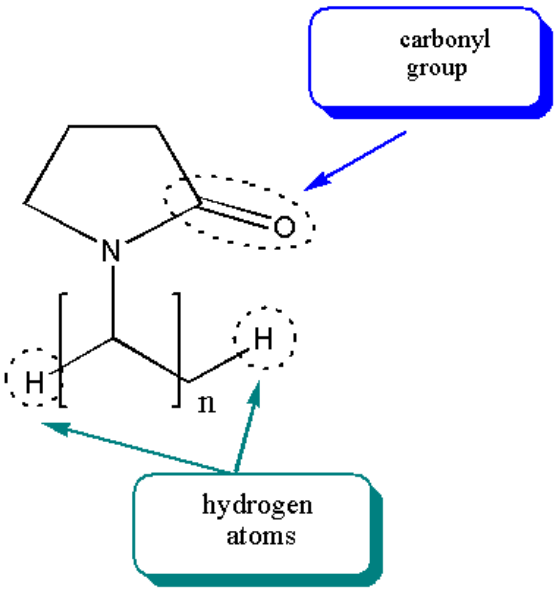


Figure 5. Polivinylpyrrolidone (PVP) functional groups.

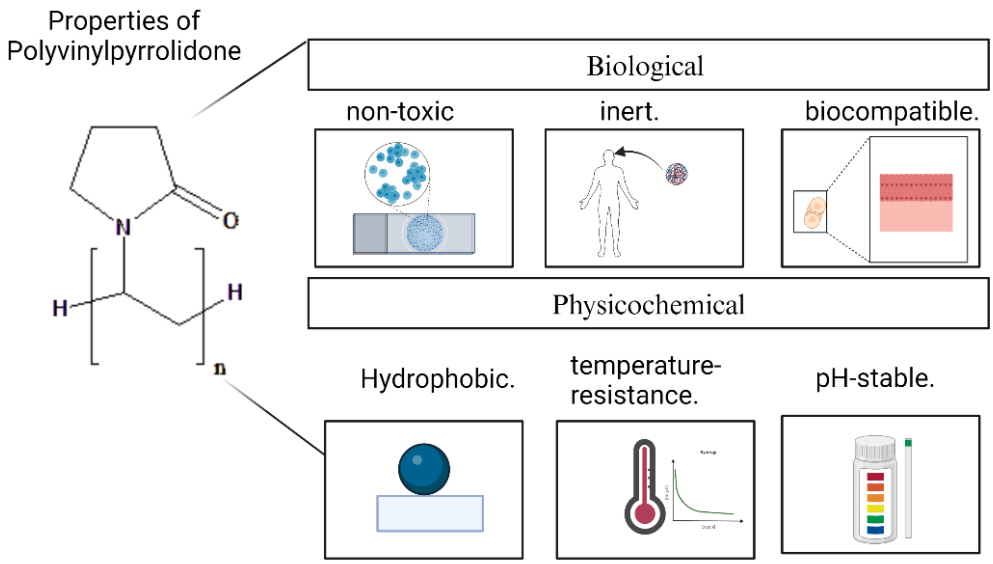


Figure 6. Biological and Physicochemical properties of Polyvinylpyrrolidone (PVP).

PVP can create thin films for transdermal drug delivery or oral disintegration. Controlled drug release can be achieved by adjusting the polymer-drug ratio and formulation conditions in PVP-based systems. Studies show that PVP possesses modifiable properties and could be used as a reinforcing element for gene delivery, tissue engineering applications, and orthopedic implants [59]. Drug release strategies can be designed depending on chemical, physical, biological, and engineering aspects, controlling the spatiotemporal release. Moreover, quantitative and controlled drug release can be achieved by adjusting the dissolving profile of the polymer matrix and drug loading [60]. PVPs are distinguished by different K-values based on the relative viscosity of PVP aqueous solution and can be used to characterize the average molecular weight of PVP [61]. The study by Unni et al. 63 mentions that hydroxypropyl methylcellulose (HPMC) and polyvinylpyrrolidone (PVP) are biocompatible synthetic polymers that can form polymeric matrices. The bioavailability of platinum nanoparticles coated with PVP has been studied, and the results show that the bioavailability is affected by the size of the nanoparticles and the composition of natural organic matter [62].

PVP-based Drug Delivery Systems (DDS).

Several important drug delivery methods for the pharmaceutical and biomedical industries have been created using PVP [63]. For example, polyvinylpyrrolidone nanofibers are a type of drug delivery system that uses PVP as a modifying component and can be used in various kinds of DDS, including micellar vehicles, nanofiber mats, and coatings for drug delivery devices [64]. Also, the spray drying procedure represents a widely adopted technique employed for converting liquid solutions or suspensions into dry powder [65] the basic scheme of this technique is shown in Figure 7.

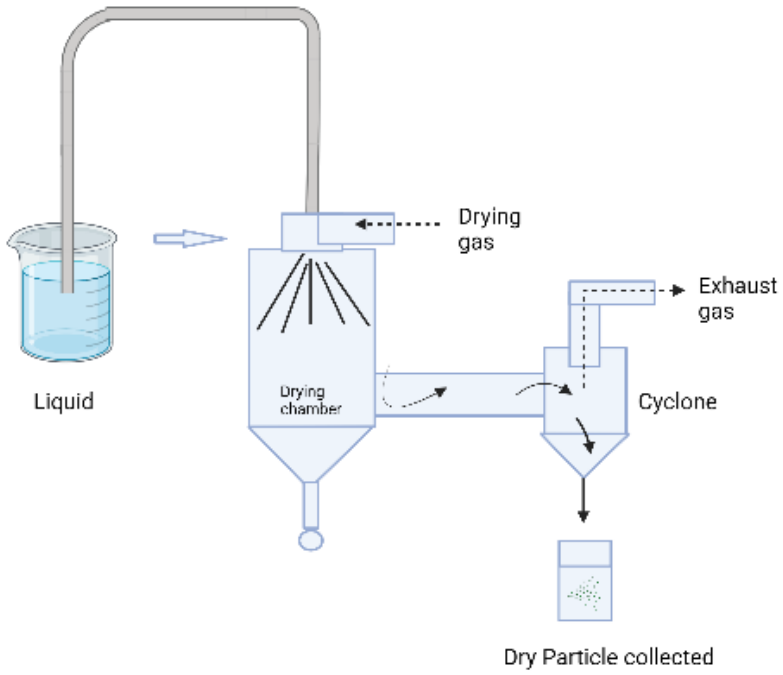


Figure 7. The spray Drying procedure is an adopted technique for converting liquid solutions or suspensions into dry powder.

Nanoparticles

In addition to its function as a stabilizing agent for nanoparticles, polyvinylpyrrolidone (PVP) is utilized to produce polymeric nanoparticles [66]. Approaching cell migration for developing new anti-inflammatory and anti-tumor medications is particularly promising [67]. For example, noble metal nanoparticles can be generated by reducing the metal salt precursor with glucose, while polyvinylpyrrolidone (PVP) serves as a stabilizing and protective agent [68]. Nanocapsules and nanospheres, as depicted in Figure 8, represent distinct nanostructures utilized in drug delivery. Figure 8a showcases nanocapsules, while Figure 8b illustrates nanospheres. These nanostructures serve as pivotal platforms for drug delivery applications. Matrix topologies are encountered in nanospheres, while a core-shell structure is a defining characteristic of nanocapsules [69].

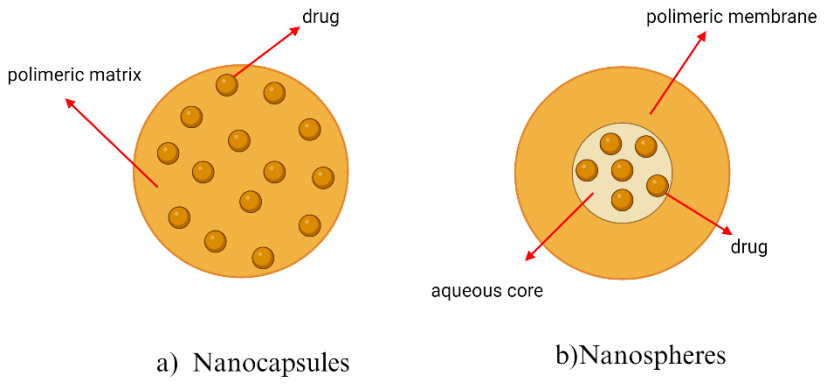


Figure 8. a) Nanocapsules and b) Nanospheres as pivotal platforms for drug delivery applications.

Microparticles

Several investigations expose the use of PVP in various formulations and structures such as nanoparticles, microparticles, fibers, and tablets [70]. A relevant technique is the supercritical antisolvent process (SAS), used for the precipitation VP microparticles, using combinations of acetone and ethanol or pure ethanol [71]. In addition, a method for the production of capillary microparticles with a PLA/PVP core by direct electrospray has been documented [72], and scientific literature also describes techniques for obtaining monodisperse microparticles from an aqueous solution of PVP [73]. These are why PVP is frequently used in the preparation of microparticles for different applications such as controlled drug release and the manufacturing of monodisperse microparticles.

Microneedles

Microneedles are an emerging transdermal drug delivery system that has gained attention recently. Polyvinylpyrrolidone (PVP) has been studied for its role in microneedles for drug delivery applications. Qiang et al. [74] created a Polyvinylpyrrolidone/Sodium Carboxymethyl Cellulose formulation; this suggests that the researchers acknowledge the potential for further enhancement in the formulation of these microneedles to ensure effective dissolution in the skin. The optimization is crucial to ensure that the microneedles can efficiently release drugs and deliver the intended therapeutic benefits.

Microcontainers

Hou et al. [75] prepared and evaluated PLA/PVP core-shell microparticles mat via single capillary electrospraying as a potential drug-loading material; however, the drug-loading capacity of the core-shell microparticles may not be as high.

Nanogels

The synthesis of PVP nanogels is carried out by different methods, such as gamma irradiation, chemical cross-linking, and self-assembly techniques [76]. Thus, gamma irradiation is a commonly used method to induce cross-linking in PVP solutions, forminganogels [77]. On the other hand, chemical cross-linking uses compounds or initiators to cross-link the PVP polymer chains and form the corresponding nanogels [78]. Finally, self-assembly techniques are based on the spontaneous assembly of PVP molecules into nanogels through interactions, such as electrostatic or hydrophobic ones [79].

Hydrogels

Hydrogel coatings can improve the molecular scaffolds' mechanical properties, making them suitable for drug delivery applications [80]. The results of the study of Pan et al. [81] indicate that adding PVP to HPMC hydrogels improves the ability of the hydrogels to adhere to the skin and release drugs sustainably since PVP increases the elasticity and resistance of the hydrogel.

Nanofibers

Polyvinylpyrrolidone (PVP) nanofibers have been proposed as a potential drug delivery system C. Virginia et al. [82] it was discovered that increasing the molecular weight of PVP resulted in the formation of fibers with larger diameters. For their preparation, electrospinning (ES) is the most sophisticated and reliable method for producing nanofibers, which provides a thorough solution to the issues with conventional approaches. This simple technique continuously removes nanofibers from a viscoelastic fluid by pulling on the electrostatic attraction between surface charges [83]. However, the low electrospinning capacity, the absence of essential qualities necessary for a specific application with a single biopolymer, and the incompatibility between common solvents are the main problems in fabricating protein nanofibers and polysaccharides using ES [84]. The general scheme of the electrospinning technique is shown in the figure 9.

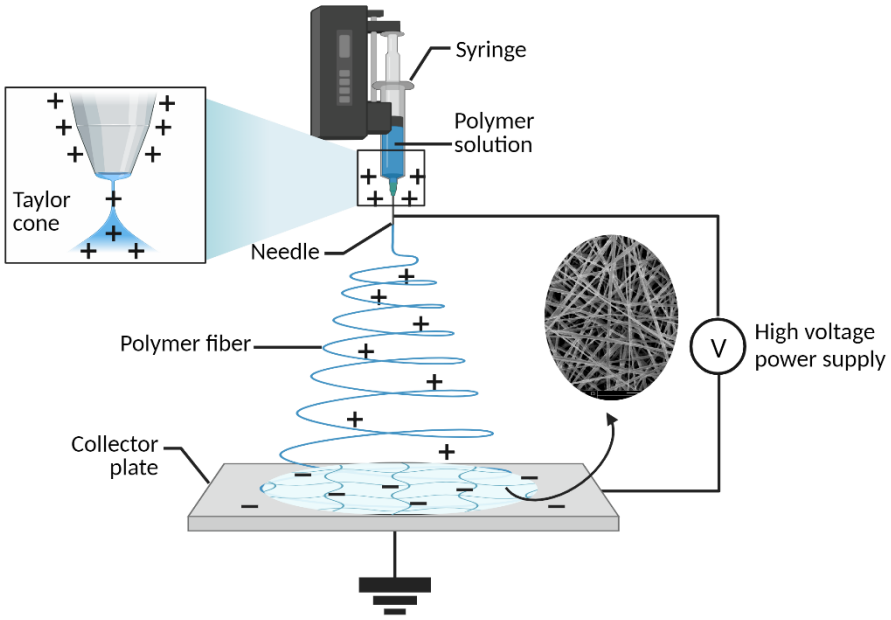


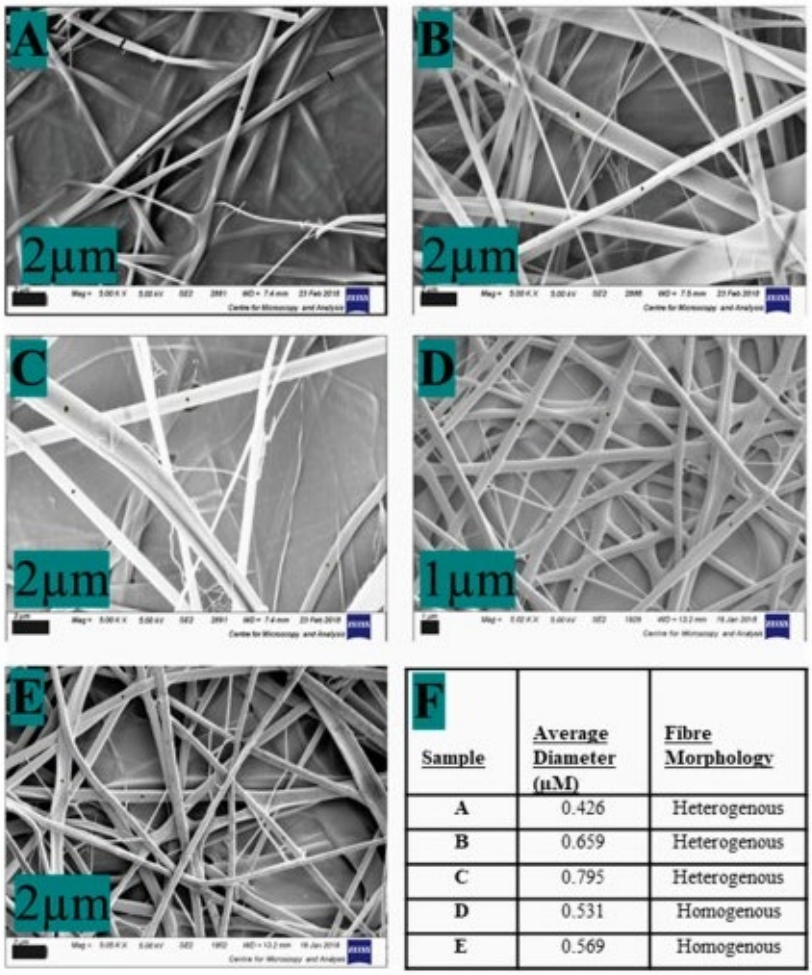
Figure 9. The electrospinning technique is the most sophisticated and reliable method for producing nanofibers.

Chitosan/PVP formulations

Detailed guidelines for chemical compounds, reactions, and laboratory procedures are known as chemical formulations or laboratory protocols. There are several reasons why formulations are of relevant importance in scientific research and industry, among which we can highlight the evaluation of the reproducibility of results, the safety of the use of reagents, the efficiency in the use of resources, and the development of new materials [85]. Chemical formulations are the bases that allow other scientists to repeat studies and obtain comparable results to evaluate and confirm the research findings. They also contribute to optimizing experimental

techniques by providing precise quantities of reagents and adequate reaction conditions, which saves time and economic resources by eliminating the need to perform tests and adjustments every time an experiment is performed. Finally, they allow researchers to design and create desired compounds with previously contemplated characteristics. This is a fundamental starting point for synthesizing new materials, medicines, and multifunctional chemical products.

In this sense, CS/PVP formulations can be proposed to create materials that can be used in various applications of scientific interest. These materials can be obtained through different processes. For example, in Christou et al. [86] study on uranium adsorption, the electrospinning process was used to create CS/PVP-based blended fibrous membrane adsorbents. On the other hand, Grant J. et al. [87,] in their research on the synthesis of chitosan/PVP fibers for the effective administration of the chemotherapeutic drug 5-fluorouracil, prepared five solutions with different formulations of chitosan, PVP, and diluted acetic acid. After the synthesis, tests, and characterization of the nanofibers, it was found that a polymer blend's ability to load and release drugs is improved by adding more CS to it. This results from how CS and 5-Fluoracil (5-F) interact [88]. They succeeded in producing fibers with a high CS-to-PVP ratio (4:6) using the fiber production protocol they developed, which has good potential for use in a drug delivery system. It is believed that a 5-Fu concentration of between 5 and 10 mg/ml would be a good bet to take advantage of the substance's cytotoxic properties for cancer research [89]. The fibers obtained with these five solutions are shown in Figure 10.



Sample	Average Diameter (µM)	Fibre Morphology
A	0.426	Heterogenous
B	0.659	Heterogenous
C	0.795	Heterogenous
D	0.531	Homogenous
E	0.569	Homogenous

Figure 10. SEM images under 5K magnification for samples obtained through Electrospun nanofibrous mats consisting of chitosan (CS) and polyvinylpyrrolidone (PVP) as potential DDS of 5-fluoracil (5-F) [89].

Advantages and Disadvantages

Producing chitosan/PVP blended fibers has an advantage over producing homogeneous chitosan fibers because, in previous studies, the miscibility and compatibility of chitosan/PVP composite mixtures have been confirmed [90]. It has been found that chitosan and PVP were immiscible in various concentrations of aqueous acetic acid [91]. As a result, the blended system can be processed by electrospinning more effectively than pure chitosan [86]. PVP was chosen because of its low cost, biocompatibility, and excellent hydrophilicity. This latter property makes their inclusion in PVP/CS fiber adsorbents more effective in increasing the adsorbent's hydrophilicity and, thus, wettability in aqueous conditions [92]. Compared to many inorganic adsorbents, polymer-based materials benefit from more excellent chemical stability, particularly in acidic environments [93]. They also exhibit improved selectivity after adding chelating groups to their surfaces, which have a significant propensity to form complexes with metal ions [94].

Natural biopolymers' biocompatibility, biodegradability, non-toxicity, and capacity to adsorb bioactive compounds make them appropriate for medicinal applications [95]. However, numerous drawbacks limit the use of natural polymers in medicine because materials exposed to the open air can adsorb pathogenic microorganisms, such as bacteria, viruses, or fungi, which can cause tissue infections [96]. Cross-contamination is a significant concern in medical settings, and using clean and sterile materials is essential to prevent the spread of diseases. For example, during manufacturing, these biopolymers are exposed to the outside environment; therefore, contamination with microbes and heavy metals is possible 99. This fact also highlights the need and importance for materials used in biomedical applications to withstand sterilization temperatures without affecting their physical, chemical, and biological properties 100.

Depending on the production method and the final applications, producing materials from biopolymers may be subject to certain drawbacks 101. For example, the main disadvantages of biopolymers in tissue engineering are their lower mechanical, chemical, and structural properties and lower stability against biodegradation 102. On the other hand, the hydrophilic nature of proteins and polysaccharides (CS and PVP, for example) prevents their use in packaging films, as it causes them to absorb moisture. To mitigate this particular problem, hydrophobic substances such as lipids can be used to reduce hygroscopicity 103.

Chitosan-Polyvinylpyrrolidone (CS-PVP) Nanocomposite for Enhanced Wound Healing

Chitosan is widely recognized for its antimicrobial properties, hemostatic ability, and ability to promote tissue regeneration. Polyvinylpyrrolidone enhances hydrophilicity and drug encapsulation, making the combination effective for wound healing.
Hydrogel-based Nanocomposites have been used in chronic wounds (e.g., diabetic ulcers) to speed up tissue regeneration and prevent infection. In this context, CS-PVP hydrogel was prepared for controlled release of wound-healing agents such as growth factors, antimicrobial drugs, or bioactive molecules (e.g., curcumin, aloe vera extract). The PVP will improve the stability and drug-loading efficiency, while CS ensures bioactivity and antimicrobial effects [102].

S-PVP Nanoparticles with Dual Drug Delivery for Multimodal Cancer Therapy

Combining chemotherapeutic agents with natural bioactive compounds (e.g., curcumin, resveratrol) can enhance therapeutic outcomes in cancer by targeting multiple pathways. Chitosan-based nanoparticles provide an excellent platform for this. Dual Drug-Loaded CS-PVP Nanoparticles have been used to deliver a

combination of synthetic chemotherapy agents and natural polyphenols (such as curcumin or resveratrol). These nanoparticles can provide a synergistic effect against cancer cells, minimizing resistance development while enhancing efficacy. A multimodal approach incorporates a photothermal or photodynamic agent in the nanoparticle, allowing for a dual approach of chemotherapy and light-activated therapy (e.g., near-infrared irradiation)[103].

CONCLUSION AND FUTURE PERSPECTIVES

As discussed in this paper, chitosan has gained interest due to its particular chemical and biological characteristics, making it a material with multiple applications in biomedicine, mainly in its drug delivery system. Also, its capacity to form gels, nanoparticles, and other controlled release systems presents a broader spectrum in this field. Biocompatibility, biodegradability, and capacity for chemical modification make chitosan a desirable molecule for improving the efficacy and safety of medical treatments. The research review confirms its adequate action in administering and releasing synthetic drugs and natural products due to its capacity to improve bioavailability, control release, and direct specific therapies.

Both chitosan and PVP have properties of interest for biomedical and non-biomedical applications. Their various individual applications have been reported in numerous investigations. However, the existing information about combining each of these biopolymers with other materials is not so extensive. Thus, it is interesting to expand the exploration of the capacity of these biopolymers to interact with different materials and therefore find properties that can be used for the benefit of society. Chemical formulations are a fundamental variable for research and industry. Knowledge and use of adequate amounts of compounds ensure expected results, quality and efficiency in the materials manufacturing processes, and reproducibility and comparability of experimental results.

The creation of CS/PVP nanofibers by electrospinning is an example of the application of chemical formulations; these nanofibers can be useful in uranium adsorption, drug delivery, and other fields. The characteristics and functions of CS/PVP nanofibers can be altered by varying the proportions and concentrations of the polymer and the test conditions.

For the creation of new materials and drug delivery systems, it is essential to consider that CS and PVP present advantages and limitations. Thus, on the one hand, they are materials that can be used for applications in industries such as biomedicine, pharmacosmetics, agriculture, and food due to their chemical stability, antimicrobial properties, hydrophilicity, biocompatibility, biodegradability, zero toxicity, and ability to form complexes with metal ions. On the other hand, by their very nature, they are susceptible to presenting difficulties for their handling, some of these being microbiological contamination, unpredictability in production procedures, low mechanical properties, extreme sensitivity to humidity, and premature deterioration in unfavorable environments. Research to improve the characteristics and functionality of biopolymers through modification, coating, addition, and combination processes can help solve the problems described above. Thanks to the scientific literature, it can be confirmed that polyvinylpyrrolidone and chitosan present an excellent window of opportunity for creating drug delivery materials and systems, as long as their benefits and limitations are

considered. Furthermore, efforts should investigate new ways to maximize their favorable characteristics while minimizing their disadvantages.

Chitosan-polyvinylpyrrolidone (CS-PVP) nanoparticles have shown significant potential in clinical practice, particularly for drug delivery, wound healing, and cancer therapy. Chitosan's biodegradability, antimicrobial properties, and ability to promote tissue regeneration make it highly suitable for biomedical applications, while PVP enhances nanoparticle stability, solubility, and drug encapsulation efficiency. In wound healing, CS-PVP nanoparticles are explored for their ability to deliver therapeutic agents in a controlled manner, promoting faster tissue repair and preventing infections in chronic wounds like diabetic ulcers. In cancer therapy, these nanoparticles are being studied for targeted drug delivery, where they can encapsulate chemotherapeutic agents or genetic material (e.g., siRNA) for controlled release at tumor sites, enhancing efficacy while reducing systemic toxicity. The biocompatibility and versatility of CS-PVP nanoparticles support their potential transition from research to clinical settings, offering promising strategies for enhanced therapeutic outcomes in various diseases.

Research should focus on two key aspects to advance drug delivery: the development of more advanced and specific formulations, aiming to optimize efficacy and reduce side effects, and the continuous improvement of characterization techniques to better understand molecular-level interactions between chitosan and drugs, enabling a more precise design of release systems. Polyvinylpyrrolidone (PVP) emerges as a flexible component for their use in various drug delivery systems. PVP-based DDS encompasses a wide spectrum of applications. However, it is imperative to continue research and optimization efforts to enhance the performance and drug-loading capacity of PVP-based microstructures, such as core-shell microparticles.

This review has shown that due to desirable characteristics such as chemical stability and selectivity, as well as biocompatibility and easy processing, chitosan (CS) and polyvinylpyrrolidone (PVP) are eligible materials for creating drug delivery systems (DDS) and materials with expected properties. However, it is necessary to deepen the scope of research on this topic to address and solve the problems of microbial contamination and biodegradability in the future, which will consequently make CS and PVP suitable for use in biomedical applications with less risk. Efforts to propose effective processing methods and research into laboratory techniques to improve these materials' mechanical characteristics and stability will eventually generate better experimental results. Finally, it is essential to mention that the study of the biomaterials subject of this review (CS and PVP) for use in the field of biomedicine and drug delivery is a task that requires multidisciplinary knowledge, so it is imperative to project efforts toward collaboration with other sciences. This, of course, will increase the opportunity to make discoveries in scientific research and the subsequent development of these materials on a large scale.

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