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NANOFIBERS BASED ON CHITOSAN AND SYNTHETIC POLYMERS: A REVIEW OF PROPERTIES AND APPLICATIONS

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Abstract: This review article is devoted to chitosan-based nanofibers combined with synthetic polymers—promising materials with a wide range of applications in biomedicine, filtration, and food packaging. Modern methods for producing such fibers are described, particularly electrospinning, as well as the influence of polymer composition on morphology, mechanical properties, solubility, water resistance, hydrophilicity, and thermal stability. The main application areas are reviewed: medical dressings, drug delivery systems, filtration membranes, and biodegradable packaging. Special attention is given to the role of synthetic polymers in improving technological and functional characteristics.

Keywords: Nanofibers, chitosan, synthetic polymers, electrospinning, PVA, PEO, PCL, food packaging, drug delivery, filtration.

Introduction. Nanofibers based on natural and synthetic polymers represent a promising class of materials due to their combination of high specific surface area, porous structure, tunable morphology, and potential for functionalization. Thanks to these characteristics, such materials find wide application in medicine, bioengineering, the food industry, filtration systems, and packaging. In recent years, particular attention has been given to the natural polymer chitosan, which is derived from chitin through deacetylation. It possesses notable antibacterial, biodegradable, and biocompatible properties, making it especially attractive for the development of medical and environmentally safe materials. However, the fabrication of nanofibers from pure chitosan presents a number of challenges related to its polycationic nature, high solution viscosity, and poor water solubility. These properties hinder the formation of a stable fibrous structure using conventional electrospinning techniques.

To overcome these challenges, chitosan is often combined with various synthetic polymers such as polyvinyl alcohol (PVA), polyethylene oxide (PEO), polyacrylonitrile (PAN), and others [1]. The incorporation of synthetic components improves the rheological properties of the solution, facilitates the electrospinning process, and enhances the mechanical strength of the resulting fibers. As a result, it becomes possible to obtain composite nanofibers that combine the biofunctionality of chitosan with the technological advantages of synthetic polymers.

This review article is devoted to current approaches for the fabrication of nanofibers based on chitosan and synthetic polymers, including an analysis of their structural, physicochemical, and biological properties, as well as an overview of the applications of these materials in various fields.

Methods. This review article is based on an analysis of scientific literature dedicated to chitosan-based and synthetic polymer-based nanofibers. The primary objective was to select and systematize data related to the fabrication methods, characteristics, and applications of these materials.

In preparing this work, peer-reviewed articles containing the results of experimental studies were taken into account, as well as review publications reflecting the current state of this scientific field. The selection of materials was based on their relevance, scientific significance, and the comprehensiveness of the data presented. Special attention was given to studies that examine technologies for the fabrication and modification of composite nanofibers, as well as comparative analyses of their properties and potential application areas.

Results and Discussion.

3.1 Methods of Nanofiber Production

The most common method for producing chitosan-based nanofibers is electrospinning. Electrospinning is a process in which ultrathin fibers are formed from a polymer solution under the influence of a strong electrostatic field and directed toward a grounded collector. Due to their high surface area-to-volume ratio and small pore sizes, such fibers find applications in a wide range of fields [1].

However, chitosan is difficult to electrospin into a fibrous structure because it exhibits a polycationic character in acidic aqueous media due to the abundance of amino groups along its main chain. Fibrous structures have been successfully formed by electrospinning chitosan solutions in 90% aqueous acetic acid, or using trifluoroacetic acid (TFA) and TFA/dichloromethane (DCM) mixtures [2]. Since electrospinning pure chitosan is challenging, it is often blended with other synthetic or natural polymers to improve solution flow properties and ensure the formation of a stable jet.

The most commonly used copolymers include:

- **Polyvinyl alcohol (PVA)** – the most frequently used copolymer; it is water-soluble and compatible with chitosan.
- **Polyethylene oxide (PEO) –** reduces solution viscosity and enhances fiber stretching.
- **Polyacrylonitrile (PAN)** – provides fiber strength but requires the use of organic solvents.
- **Polycaprolactone (PCL)** – a biodegradable polymer that improves the mechanical properties and structural stability of the fibers.

These additives enhance the solution's flow properties, stabilize the jet during electrospinning, and facilitate the formation of a uniform fibrous structure.

3.2 Physicochemical Properties of Nanofibers

The physicochemical properties of nanofibers based on chitosan and synthetic polymers determine their suitability for various applications, such as medicine, packaging, and filtration. Key characteristics include morphology, mechanical strength, solubility, water resistance, hydrophilicity, and thermal stability.

Morphology and Fiber Diameter:

Studies have shown that the addition of synthetic polymers such as polyvinyl alcohol (PVA) to chitosan facilitates the formation of more uniform and finer fibers during electrospinning.

Scanning Electron Microscopy (SEM) analysis revealed that the diameter of chitosan/PVA blend fibers ranges from 132 to 212 nm, indicating improved morphology compared to pure chitosan [3].

Mechanical Properties:

The incorporation of PVA enhances the mechanical characteristics of the nanofibers.

Composite fibers exhibit increased tensile strength and elasticity, making them suitable for biomedical applications [4].

Solubility and Water Resistance:

Pure chitosan is soluble in acidic media, whereas chitosan/PVA composites show greater resistance to water and physiological solutions.

This resistance can be further improved through thermal treatment or crosslinking.

Hydrophilicity and Swelling Capacity:

Composite fibers demonstrate high hydrophilicity due to the presence of hydroxyl and amino groups.

This facilitates moisture retention and makes the fibers suitable for controlled drug delivery systems, as well as for cosmetic and medical applications.

Thermal Stability:

Thermogravimetric analysis (TGA) shows that composite fibers possess sufficient thermal stability for most biomedical and packaging applications.

The inclusion of synthetic polymers may either enhance or slightly reduce thermal resistance, depending on their nature and ratio to chitosan.

3.3 Applications of Chitosan-Based and Synthetic Polymer Nanofibers

Nanofibers based on chitosan and synthetic polymers find widespread use due to their combination of biocompatibility, antimicrobial properties, and improved physicochemical characteristics.

Medicine and Biomedicine:

One of the most promising areas is the use of such fibers in wound dressings, medical bandages, drug carriers, and scaffolds for tissue engineering.

Chitosan promotes wound healing and exhibits hemostatic and antimicrobial effects, while synthetic polymers enhance mechanical strength and control degradation behavior.

Chitosan is among the polymers that are actively studied for the production of wound dressings due to its unique properties, such as wound healing and bacteriostatic effects, as well as high biocompatibility and biodegradability [5]. However, the fabrication of pure chitosan nanofibers via electrospinning presents challenges because of the high viscosity and poor electrospinnability of aqueous chitosan solutions. To facilitate nanofiber formation, chitosan is often blended with other spinnable polymers, such as polyvinyl alcohol (PVA) [6]. PVA is a water-soluble, fully biodegradable, non-toxic, and biocompatible polymer that is widely used in biomedicine, including the manufacture of wound and tissue repair dressings [7].

Filtration and Purification:

Composite nanofibers based on chitosan and synthetic polymers are used in water and air filtration systems due to their high porosity, large specific surface area, and the presence of functional groups. Chitosan has the ability to adsorb heavy metals, dyes, phenols, microorganisms, and other pollutants through its amino groups, which interact with contaminants. Nanofibrous membranes can be employed as filters for wastewater treatment, antibacterial air filtration, and as nanomaterials for reverse osmosis. The incorporation of synthetic polymers such as PEO (polyethylene oxide) or PAN (polyacrylonitrile) enhances the mechanical strength and structural stability of the fibers in aqueous environments [8].

Food Packaging:

Biodegradable fibrous systems based on chitosan are used in the production of active food packaging. Chitosan provides antimicrobial protection for food products, while the fibrous structure forms a gas barrier, contributing to extended shelf life. Blending chitosan with polymers such as polyethylene oxide (PEO) and polycaprolactone (PCL) enhances the mechanical strength and moisture resistance of packaging materials.

Drug Delivery:

Chitosan nanofibers are actively studied as efficient carriers for the delivery of various therapeutic molecules, including genes, proteins, and pharmaceutical drugs [9]. Due to its cationic nature, biocompatibility, and biodegradability, chitosan can form stable complexes with nucleic acids, protecting them from degradation and promoting effective cellular uptake. Moreover, chemical modification of chitosan can improve its solubility and enable targeted delivery of therapeutic agents.

Conclusion. Nanofibers based on chitosan and synthetic polymers represent a promising class of materials due to the combination of natural biological properties and enhanced physicochemical characteristics. Electrospinning remains the primary method for their fabrication, while the incorporation of synthetic polymers helps to overcome the technological limitations associated with pure chitosan. The analysis shows that such composite materials are effectively applied in medicine (including wound dressings and drug delivery systems), filtration technologies, and the food industry. Future research should focus on optimizing fiber composition, improving their stability, and adapting fabrication processes for large-scale production.

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