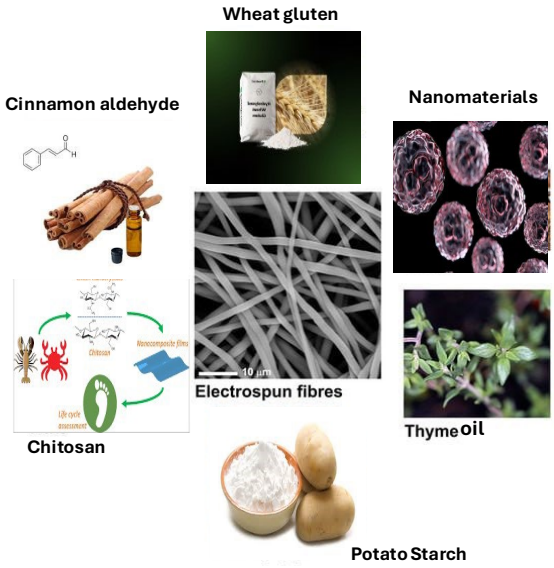
# Electrospun Bio-based Nanofibers for Wound Healing Materials: Protein and Starch-Based Systems

Sanjit Kumar Singh

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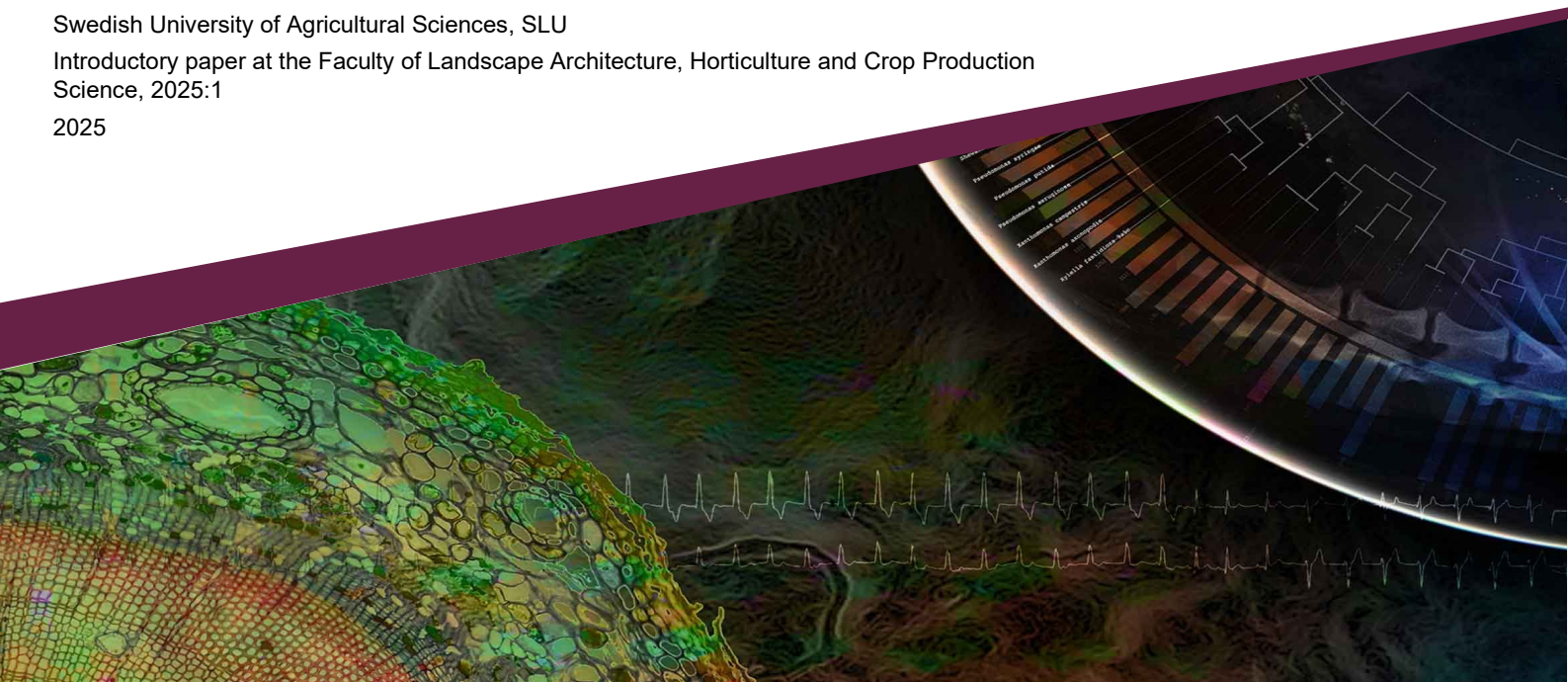

Electrospun Bio-based Nanofibers for Wound Healing Materials: Protein and Starch-Based Systems

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# Abbreviations

| | |
|---|---|
| SLU | Swedish University of Agricultural Sciences |
| HFIP | 1,1,1,3,3,3-Hexafluoro-2-propanol |
| HAc | Acetic acid |
| PVA | Poly(vinyl alcohol) |
| PEO | Poly(ethylene oxide) |
| PCL | Poly(ε-caprolactone) |
| WG | Wheat gluten |
| SPI | Soy protein isolate |
| ECM | Extracellular matrix |
| PBS | Phosphate-buffered saline |
| GLA | Glutaraldehyde |
| DTT | Dithiothreitol |
| 2-ME | 2-Mercaptoethanol |
| RH | Relative humidity |

**Summary**

Electrospinning enables the fabrication of ultrafine polymer fibers offering high surface area, interconnected porosity, and tunable chemistry for advanced wound dressing materials. Driven by sustainability goals, plant-derived proteins (zein, soy protein, wheat gluten) and polysaccharides (starch, cellulose, chitosan) are emerging as renewable potential alternatives to replace some of petroleum-based materials. In addition to plant-derived protein-polysaccharide systems, this review also discusses animal-derived proteins (collagen, gelatin, and silk fibroin), as well as microbial polymers (such as bacterial cellulose), serving as fibrous materials for understanding the structure–function relationships and bioactivity of natural electrospun fibers in absorbents and wound healing materials. These materials highlight how different protein origin and molecular architecture influences electrospinnability, mechanical integrity, and biological performance. This introductory paper also focusing on the use of various types of proteins, including wheat gluten (gliadin/glutenin) and polysaccharides such as potato starch and chitosan use in formulations, processing, and performance of fibrous materials.

Natural polymers present some challenges (e.g. large solubility, instability in water, batch variability) in order to be used in absorbent and wound dressings, although these challenges can be partly mitigated through selection of greener solvent systems (ethanol/acetic-acid aqueous), polymer blending (PVA/PEO/PCL/PHA), and post-processing (citric-acid or glutaraldehyde crosslinking, heat treatment). From the plant proteins, zein easily electrospins from ethanol-rich media and efficiently loads hydrophobic active components (e.g., curcumin). Soy protein isolate typically requires water-borne blends to achieve spinnability. Wheat gluten proteins benefit from the use of reducing agents (e.g., β-mercaptoethanol or dithiothreitol), which disrupt disulfide bonds and improve chain mobility, thereby enhancing their electrospinnability. The gluten proteins can be electrospun from blended systems with ethanol–acetic acid solvents or with carrier polymers such as PEO or PVA to produce uniform and continuous fibers. The gluten proteins have been also electrospun with antimicrobial compounds (nisin, glycerol monolaurate) for active packaging and wound care.

High-amylose starch improves fiber formation when electrospun into fibrous materials and enables controlled release, while CRISPR/Cas9 editing of starch branching enzymes offers a route to tailor amylose/amylopectin ratios for better electrospinnability and improve starch use in bio-based materials applications. Cellulose and chitosan are promising components which can improve the bio-based materials functional properties, though solvent choice and process optimization remain to be optimized and improved.

Across systems, electrospun mats from the plant based polymers can be further explored in bio-based materials to manage moisture balance, cell adhesion, and localized, sustained delivery of bioactives (including essential-oil components such as cinnamaldehyde), with potential to reduce infection and antibiotic use, though further work should be explored in the area of wound healing materials. Future priorities include the plant based protein materials and starch use for absorbents and wound healing in order to improve scalability, needleless/roll-to-roll processes with solvent recovery, robust structure–processing and processing optimization/adaptation for larger scale industrial production, as well as clinical trials (cytocompatibility, allergenicity etc.). By valorizing agricultural protein rich side streams and starch raw materials suitability for bio-

materials, an emphasis lays on finding new ways to improve the circular bioeconomy and advance development of novel bio-based materials for wound-care applications.

## 1. Introduction

The transition from petroleum-derived synthetic polymers to bio-based and naturally derived polymers—including both bio-synthesized polymers (e.g., polylactic acid, PLA) and naturally occurring biopolymers (e.g., proteins and polysaccharides)—has become increasingly prominent in recent years (Han et al., 2022). While polymers such as PLA and polyurethane (PU) (Hall Barrientos et al., 2019; Unnithan et al., 2015) have demonstrated excellent spinnability and mechanical performance, their processing often relies on organic solvents or lacks inherent bioactivity. In contrast, naturally derived polymers like collagen, gelatin, chitosan, silk, zein, soy protein, and starch can often be processed in greener solvent systems (e.g., ethanol–acetic acid aqueous mixtures) and offer intrinsic biocompatibility and biofunctionality, making them attractive for wound-healing applications.

As illustrated in Figure 1, electrospun nanofibers fabricated from natural polymers (collagen, gelatin, chitosan, fibrinogen, silk, hyaluronic acid) and plant-based materials (zein, soy protein, wheat gluten, starch, cellulose) interact with different wound-healing phases—providing anti-inflammatory and antibacterial activity during the inflammatory stage, and promoting angiogenesis, cell proliferation, and extracellular matrix remodeling during the proliferative and remodeling stages. These multifunctional bio-based systems exemplify the ongoing transition toward sustainable and therapeutic wound dressing materials.

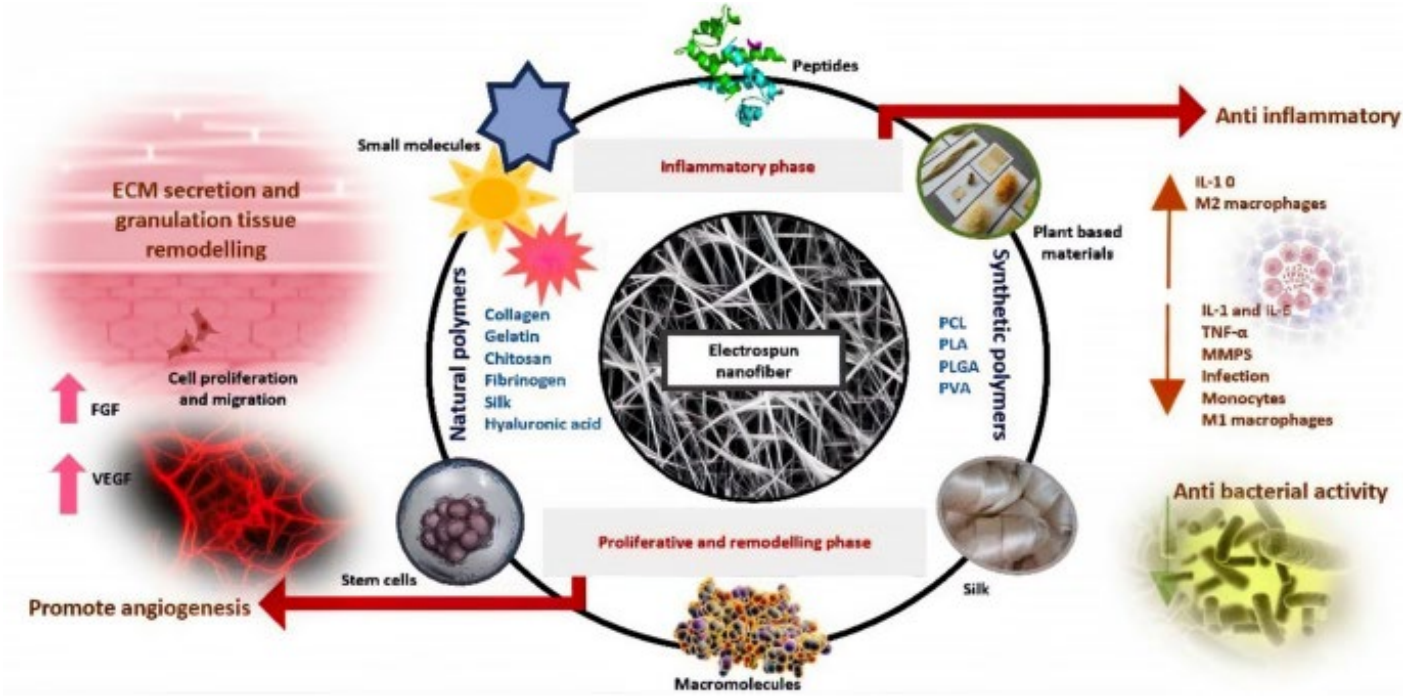


**Figure 1. Schematic comparing synthetic and natural polymers used in electrospinning. Adapted from Palani et al. (2024).**

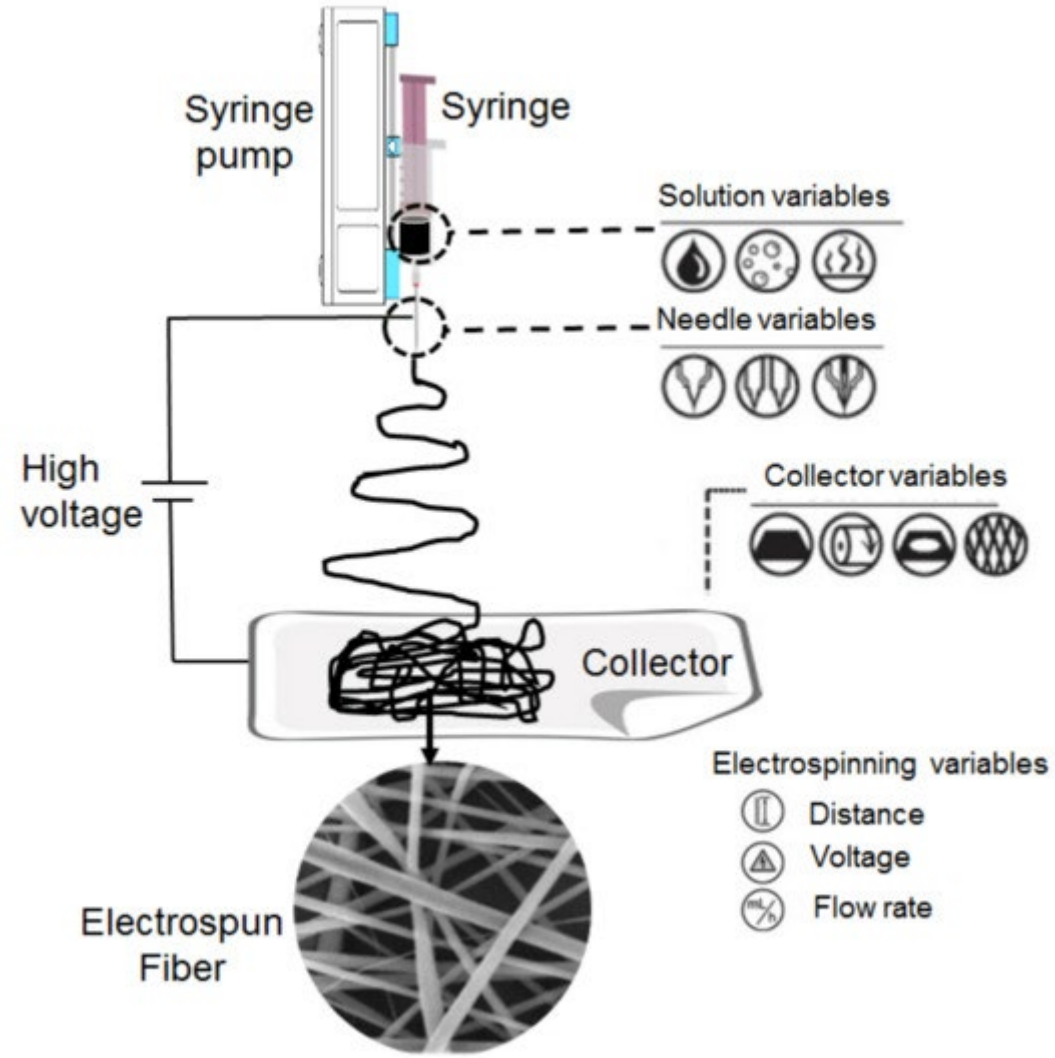


**Figure 2. Basic electrospinning setup showing the Taylor cone, charged jet, and fibre collector. Adapted from Fadil et al. (2021a).**

Natural polymers such as zein, soy protein isolate, pea protein, bean protein concentrate, gelatin, collagen, and silk fibroin pose several challenges regarding fabrication and reproducibility. The

concentrate (BPC)—is highly sensitive to solvent evaporation rate, surface tension, and electrical conductivity (Aguilar-Vázquez et al., 2020). In that study, PPI and BPC were electrospun using various solvents (hexafluoroisopropanol, trifluoroethanol, trifluoroacetic acid, formic acid, and water) to assess their rheological and conformational behavior. Both protein systems exhibited pseudoplastic flow, with β-type turns and β-sheets as the dominant conformations in HFIP, TFE, and water. However, only BPC dissolved in HFIP produced continuous fiber-like morphologies, highlighting that solvent vapor pressure and solution viscosity play crucial roles in fiber formation. This study demonstrates the importance of selecting appropriate solvents to achieve partial protein unfolding and sufficient chain entanglement required for successful electrospinning.

Electrospinning of proteins is further complicated by intrinsic factors such as molecular-weight distribution, surface charge, and the presence of ionic, hydrogen, and disulfide bonds (Aguilar-Vázquez et al., 2020). Successful fiber formation depends on adequate solubility, partial

unfolding of the protein chains (Aguilar-Vázquez et al., 2020; Mendes et al., 2017), and sufficient chain entanglement (Woerdeman et al., 2005). The chosen solvent strongly influences fiber crystallinity, mechanical integrity, morphology, and average diameter (Aguilar-Vázquez et al., 2020). Consequently, blending these proteins—typically of plant origin (zein, soy protein, wheat gluten) or animal origin (gelatin, collagen, silk fibroin)—with compatible synthetic polymers such as poly(ethylene oxide) (PEO), poly(vinyl alcohol) (PVA), polycaprolactone (PCL), or polylactic acid (PLA) is often required to produce continuous, defect-free fibers.

Proteins are especially promising as carriers in antimicrobial and therapeutic delivery systems because of their natural origin, biodegradability, and cytocompatibility (DeFrates et al., 2018). Electrospun protein-based fibers for wound-healing applications have been fabricated from both plant proteins (zein, soy, gliadin) and animal proteins (collagen, gelatin, silk fibroin(DeFrates et al., 2018). However, their stability and degradation profiles vary with molecular size, chemical structure, and isolation technique (Ramírez-Rodríguez et al., 2022). Variations introduced during extraction and purification can alter protein purity and conformation of processing material, thereby influencing electrospinning reproducibility and the final fiber performance of zein, soy, or collagen systems (Aytac et al., 2020; Dai et al., 2025; Reddy & Yang, 2007).

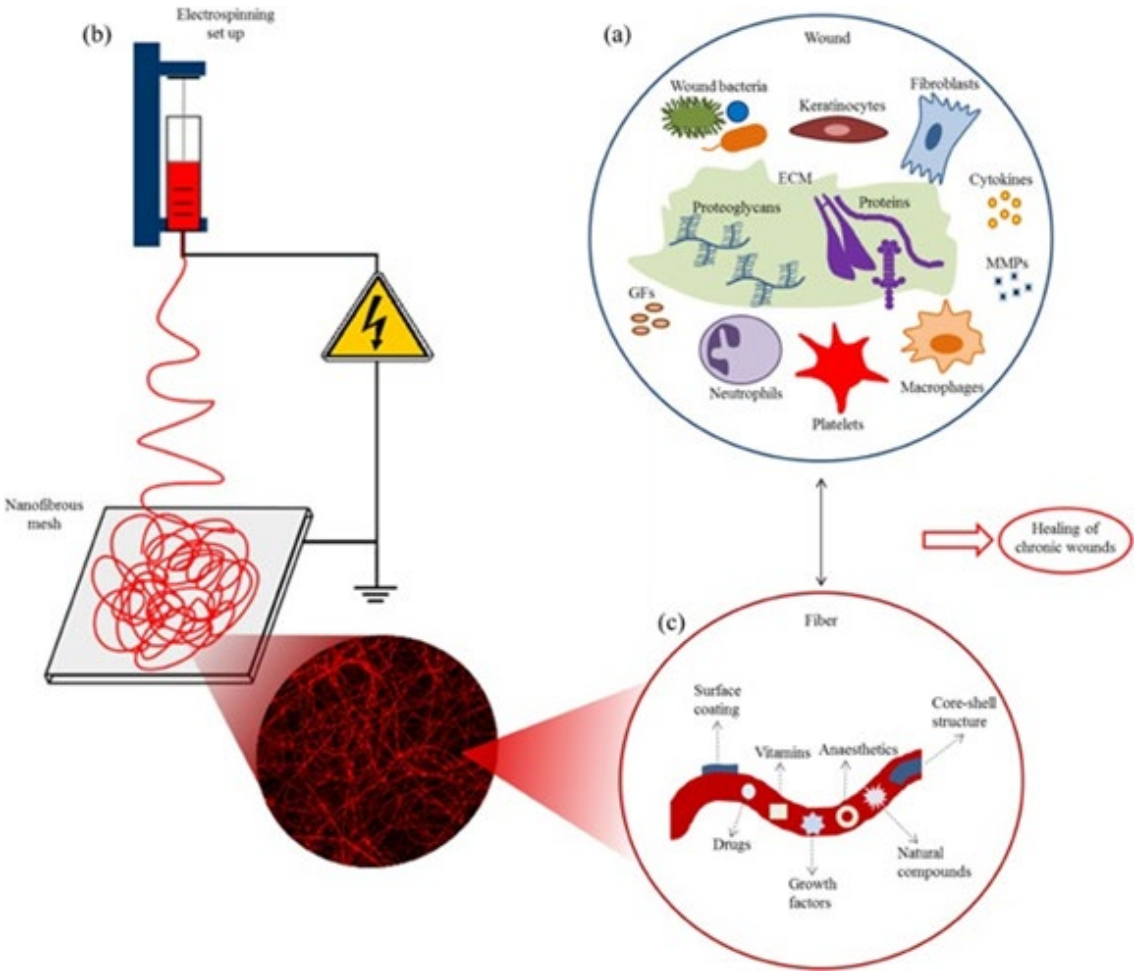


**Figure 3. Four stages of wound healing (hemostasis, inflammation, proliferation, and remodelling) and nanofiber–tissue interactions. Adapted from Abrigo et al. (2014).**

Plant-derived proteins are typically more abundant and cost-effective than animal proteins (DeFrates et al., 2018) but are often more difficult to electrospin because of structural heterogeneity, charge sensitivity, and low solution viscosity. Solvent-induced conformational changes frequently cause inconsistent jet stability and bead formation (Sarkar et al., 2018). Moreover, electrospun protein mats from zein, soy protein isolate, and wheat gliadin usually lack water stability, as they readily swell or dissolve upon hydration usually lack water stability, easily swell or dissolve upon hydration (Kanjanapongkul et al., 2010; Vogt et al., 2018a). To mitigate these issues, a number of studies have employed protein crosslinking, blending with other polymers, and solvent optimization strategies (Stie et al., 2022).

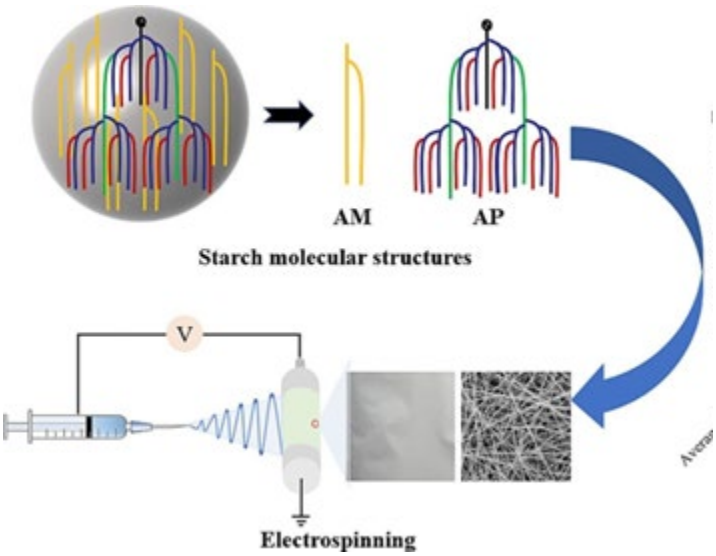


**Figure 4. Molecular structures of amylose (linear) and amylopectin (branched) illustrating their influence on electrospinnability. Adapted from Cao et al. (2022).**

In addition to proteins, starch—composed of the two molecules amylose and amylopectin—represents another versatile bio-based material for electrospinning. The essentially linear amylose molecule promotes molecular entanglement and fiber continuity, whereas the highly branched amylopectin disrupts chain alignment (P. Cao, 2022). High-amylose starches from corn (Gelose 80, Hylon VII, Hylon V) (Kong & Ziegler, 2012, 2013; Lancuški et al., 2015; Shu Liu et al., 2017) and potato (Cárdenas et al., 2016) have demonstrated good electrospinning potential. Fiber uniformity and mechanical strength of fiber materials from starch originating from diverse sources can be enhanced by blending starch with pullulan (S. Li et al., 2021), chitosan (Adeli et al., 2019), or poly(vinyl alcohol) (PVA) in combination with starch from mango kernels (Gomez-Caturla et al., 2022;) rice starch (Jaiturong et al., 2018) and Sechium edule starch (Porras-Saavedra et al., 2022).

The skin, the body's largest organ is commonly maintaining hydration, temperature, and electrolyte balance while protecting against physical, chemical, and microbial threats (X. Zhang et al., 2024a). When this barrier is damaged by burns, trauma, or chronic lesions, infection and dehydration may ensue. Healing progresses is known through four overlapping stages—hemostasis, inflammation, proliferation, and remodeling—but infection and oxidative stress can delay these processes (Juncos Bombin et al., 2020). Conventional dressings such as gauze and cotton provide passive protection yet suffer from dehydration, poor oxygen exchange, and

adhesion to the wound site. These drawbacks have stimulated the development of advanced bioactive dressings, particularly electrospun nanofiber scaffolds that offer a moist, permeable, and biologically supportive interface (Abrigo et al., 2014).

Electrospinning produces ultrafine fibers that mimic the extracellular matrix (ECM), supplying mechanical support and biochemical cues for cell attachment and proliferation. The high surface-area-to-volume ratio and interconnected porosity of nanofiber mats facilitate gas exchange and moisture retention while enabling the incorporation of bioactive molecules such as antimicrobial components, growth factors, antioxidants, and essential oils (Akman et al., 2019; Vogt et al., 2018b; Wnek et al., 2003)). Synthetic polymers like poly(DL-lactic-co-caprolactone) (PLCL) and polycaprolactone (PCL) contribute with mechanical durability, whereas natural polymers enhance bioactivity and degradability (Lanno et al., 2020). Hybrid combinations of the two classes provide balanced mechanical and biological properties tailored to wound-healing needs ( Zhang et al., 2020).

Plant-based proteins such as soy protein, wheat gluten, gliadin, and zein have gained particular attention for their biocompatibility, antioxidant potential, and ability to stimulate cell migration (Feng et al., 2019; Reddy & Yang, 2007). Challenges remain, including optimizing plant-protein structure and processing for fibrous material applications—considering raw material availability, protein denaturation during electrospinning, the need for crosslinking to achieve aqueous stability, appropriate tensile strength, and maintained biological functionality. Nevertheless, incorporation of natural antimicrobial compounds such as cinnamaldehyde, thymol, eugenol, or tea tree oil within fibers from these plant proteins can yield multifunctional wound dressings (Rezaeinia et al., 2025)capable of providing both physical protection and active antimicrobial healing functions.

Similarly, starch-based electrospun fibers have demonstrated effectiveness as carriers for bioactive compounds such as curcumin, ciprofloxacin, and essential oils, protecting these molecules from humidity, light, and thermal degradation while allowing controlled and sustained release(Liu et al., 2017). Such starch-based composite fiber systems, particularly when loaded with therapeutic agents, have been widely studied in pharmaceutical (Jaiturong et al., 2018), biomedical (Komur et al., 2017), and wound-healing (Adeli et al., 2019) applications. By localizing and sustaining drug delivery, and sustaining the release of bioactive compounds, these starch-based electrospun systems promote tissue regeneration, angiogenesis, and accelerated wound closure, thereby enhancing the overall healing process(Palanisamy et al., 2022).

This review therefore examines the role of bio-based nanofibers from diverse protein and starch raw materials in wound healing, with emphasis on wheat-derived gluten proteins and starches obtained from wheat and potato. It explores the materials physicochemical properties, electrospinning behavior, and potential for incorporating bioactive compounds. Finally, it highlights the challenges and opportunities in developing eco-friendly, sustainable wound dressings derived from polymeric nature agricultural by-products that unite biocompatibility, biodegradability, and therapeutic performance in next-generation wound-care solutions.

## 2. Electrospinning Process

Electrospinning is a versatile and scalable technique for fabricating ultrafine fibers from polymer solutions or melts, producing diameters ranging from micrometers down to tens of nanometers. The process exploits the interaction between electrostatic forces and viscoelastic fluid properties, yielding continuous fibers with exceptionally high surface-area-to-volume ratios and tunable morphologies. Owing to its simplicity, adaptability, and low cost, electrospinning has become a cornerstone technology for nanofibrous materials in biomedical engineering, drug delivery, filtration, sensors, and active packaging (Jain et al., 2020; Melendez-Rodriguez et al., 2020; Wilk & Benko, 2021).

When a high-voltage electric field is applied to a polymer solution or melt in a syringe tipped with a metallic needle, electrostatic forces overcome the surface tension of the fluid droplet. A charged jet is ejected, forming the characteristic Taylor cone. As the jet travels toward a grounded collector, it elongates, undergoes whipping instabilities, and solidifies as the solvent evaporates—depositing a non-woven mat of continuous nanofibers (Fadil et al., 2021b).

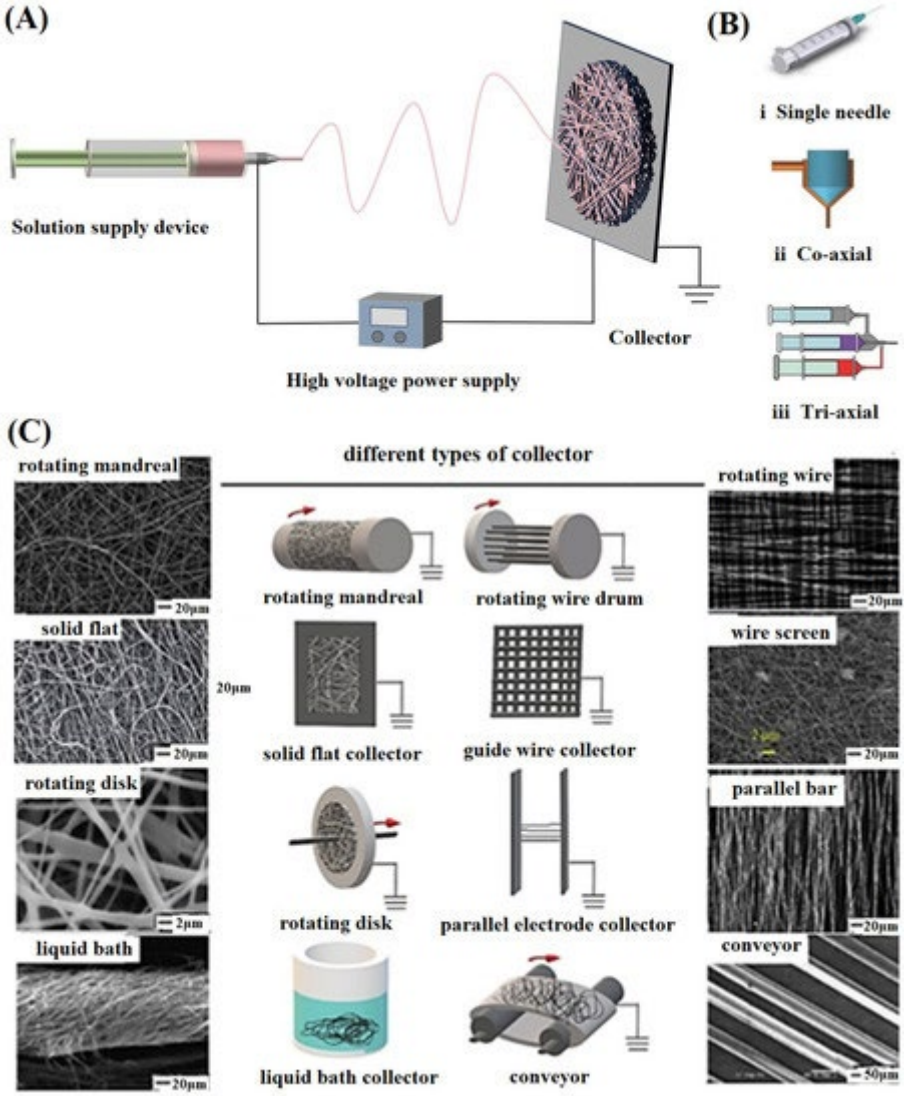


**Figure 5. Basic electrospinning setup comprising a high-voltage power supply, syringe pump, and static or rotating collector. Adapted from Yang and Xu (2023).**

### 2.1 Influence of Parameters on Fiber Morphology

The morphology and quality of electrospun fibers depend on a delicate balance among **solution**, **process**, and **environmental** parameters. Optimizing these interrelated variables ensures uniformity, prevents bead formation, and controls mechanical performance. As summarized in Table 1, key electrospinning parameters—including polymer concentration, solvent composition, applied voltage, flow rate, tip-to-collector distance, and ambient humidity—collectively govern fiber diameter, surface morphology, and structural integrity.

**Table 1. Key electrospinning parameters and their influence on fiber morphology**

| Parameter Type | Examples | Effect on Fibers | Typical Range |
|---|---|---|---|
| Solution | Concentration, viscosity, conductivity | Too low → beads; optimum → uniform fibers | 5–25 wt % |
| Process | Voltage, flow rate, tip–collector distance | Higher voltage → finer fibers; longer distance → full solvent evaporation | 10–25 kV; 0.2–1 mL $h^{-1}$; 10–20 cm |
| Environment | Temperature, humidity | High RH → porous fibers; low RH → dense fibers | 20–30 °C; 40–60 % RH |

Adapted from (Fadil et al., 2021b).

### 2.2 Process Optimization for Biopolymers

Natural polymers present additional challenges because of their limited solubility, variable molecular weight, and tendency toward insufficient chain entanglement. Strategies such as polymer blending, solvent-system tuning, and surfactant or crosslinker incorporation to improve electrospinnability are needed (Haghi & Akbari, 2007; Pillay et al., 2013).

### 2.3 Advantages of Nanofiber-Based Wound Dressings

Electrospun nanofibers possess structural and functional attributes ideal for wound-healing applications:

- **High surface area and porosity** enabling efficient gas exchange and moisture balance.
- **Extra cellular matrix (ECM)–like topography** that promotes fibroblast adhesion, migration, and proliferation (Abrigo et al., 2014).
- **Functionalization flexibility** allowing incorporation of antimicrobial agents, growth factors, and antioxidants to accelerate tissue repair (Feng et al., 2019).

### 2.4 Materials and Their Impact on Wound Healing

Synthetic polymers such as polylactic acid (PLA) and polyurethane (PU) offer mechanical robustness but often require toxic solvents, raising environmental and biocompatibility concerns (Hall Barrientos et al., 2019; Tiwari et al., 2017). Conversely, natural polymers—including wheat-derived gliadin and starches from wheat and potato—provide excellent **biocompatibility** and **biodegradability**, and can be processed using milder solvents such as aqueous ethanol, acetic acid, or formic acid solutions, often in combination with small amounts of water or benign co-solvents (Fonseca et al., 2020; Reddy & Yang, 2007).

**Table 2. Comparison of synthetic and natural polymers used for electrospinning**

| Polymer Type | Advantages | Limitations | Common Solvent System | Reference |
|---|---|---|---|---|
| Polylactic acid, Polyurethane | High strength, durability | Require toxic solvents ($CHCl_3$, DMF) | DMF/DCM mixtures | (Wu et al., 2022), (Demir et al., n.d.) |
| Poly-caprolactone), Poly(Lactic-co-Glycolic Acid) | Biodegradable synthetics | Slow degradation | DCM, acetone | (Ginestra et al., 2016) (Herrero-Herrero et al., 2021) |
| Gliadin, Zein Protein-based biopolymer (prolamin class; amino acid polymer). | Biocompatible, bioactive | Low viscosity, aqueous instability | Ethanol–water | (Kim, 2011). |
| Starch, Chitosan | Renewable, antimicrobial | Poor spinnability alone | Acetic acid or ethanol–water | (Kong & Ziegler, 2014) (Tamzid et al., 2024) |

### 3. Wound-Healing Process and the Role of Electrospun Nanofibers

Wound healing is a multistage biological process encompassing **hemostasis**, **inflammation**, **proliferation**, and **remodeling**. Each phase relies on an orchestrated interplay of cells,

cytokines, and extracellular matrix (ECM) components to restore tissue integrity (Lanno et al.,2020).

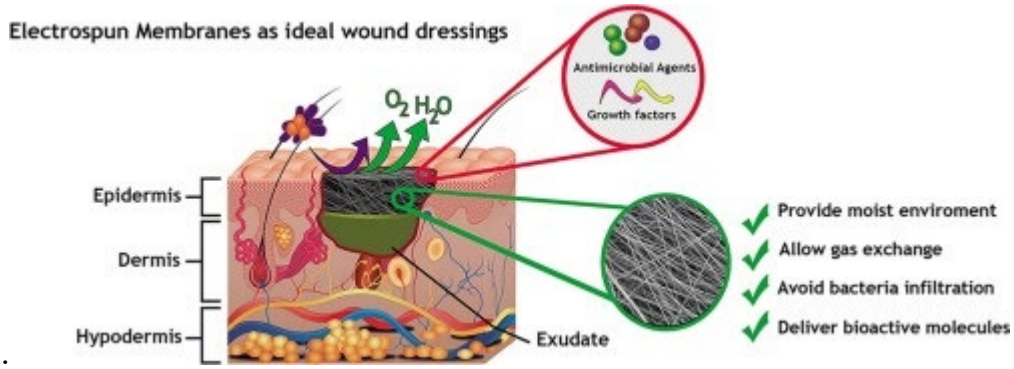


**Figure 6. Schematic representation of electrospun nanofiber wound dressings showing porosity, ECM mimicry, and bioactive loading. Adapted from Miguel et al. (2018)**

Some conventional wound dressings provide passive protection, while electrospun nanofibers are expected to guide a better repair of skin by mimicking the fibrous ECM and enabling localized delivery of drugs or antimicrobial compounds (Abrigo et al., 2014).

### 3.1 Antimicrobial Properties of Nanofibers

Infection remains one of the greatest challenges to wound management requiring effective functional properties from the dressing materials. Nanofibers fabricated from gliadin, gluten, and chitosan can potentially exhibit intrinsic antimicrobial activity, and when incorporated with antimicrobial compounds may contribute to reduction of bacterial colonization at the wound surface (Reddy & Yang, 2007; Y. Zhang et al., 2020). While starch-based fibers incorporated with essential oils and antimicrobial agents can also enhance protection against bacteria (Komur et al., 2017).

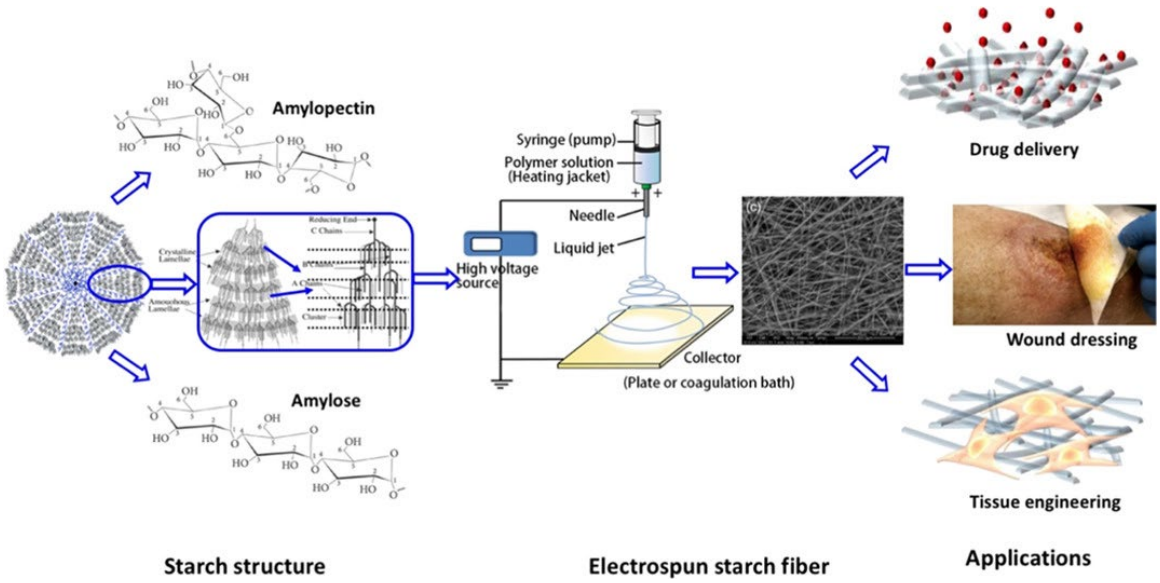


**Figure 7. Mechanism of antimicrobial action of starch-based electrospun nanofibers. Adapted from Adeli et al. (2019).**

### 3.2 Biocompatibility and Cytocompatibility

Electrospun nanofibers possess structural and functional attributes ideal for wound-healing applications: high surface area and porosity enabling efficient gas exchange and moisture balance, and extracellular matrix (ECM)-like topography that promotes fibroblast adhesion, migration, and proliferation (Abrigo et al., 2014). Natural polymer nanofibers—especially those based on gliadin and zein— in blends with ε-caprolactone further support fibroblast and keratinocyte adhesion and proliferation, confirming their cytocompatibility and suitability for tissue regeneration (Jing et al., 2024).

### 3.3 Controlled Release of Therapeutic Agents

Electrospun nanofibers can encapsulate drugs and bioactive compounds that can be released in a controlled manner, ensuring sustained therapeutic concentration and reduced dressing-change frequency (Adeli et al., 2019; Palanisamy et al., 2022).

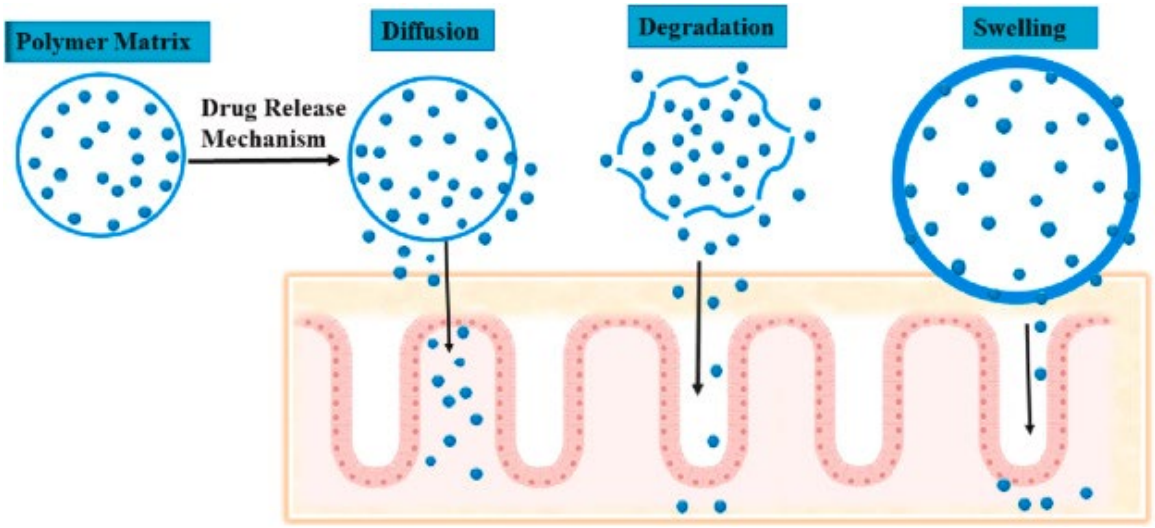


**Figure 8. Controlled-release mechanisms of drugs and bioactive compounds from electrospun nanofibers, including diffusion, polymer degradation, and swelling. Adapted from Palanisamy et al. (2022).**

### 3.4 Tissue Regeneration and Scar Prevention

By providing an ECM-like scaffold and maintaining a moist microenvironment, electrospun fibers from natural polymers such as collagen, gelatin, chitosan, silk fibroin, zein, and soy protein, as well as synthetic biopolymers such as poly(ε-caprolactone) (PCL), poly(lactic acid) (PLA), and poly(lactic-co-glycolic acid) (PLGA), may promote collagen deposition and fibroblast proliferation, thereby accelerating re-epithelialization and minimizing scarring (Abrigo et al., 2014). The mechanical properties of these fibrous materials can be tuned to approximate native skin elasticity, further supporting tissue integrity (see Table 3).

**Table 3. Bio-based electrospun nanofibers and their biomedical functions**

| Polymer System | Bioactive Agent | Key Function | Reference |
|---|---|---|---|
| Gliadin + Cuminldehyde | Essential oil | Antimicrobial, anti-inflammatory | (Hajjari et al., 2021) |
| Starch + Chitosan | – | Structural support, gas permeability | (Adeli et al., 2019) |
| Zein + Curcumin | Polyphenol | Antioxidant, anti-scarring | (Feng et al., 2019) |
| PCL + Collagen | Growth factors | Enhanced epithelialization | (X. Zhang et al., 2024b) |

If the bio-based electrospun nanofibers could combine antimicrobial protection, controlled drug release, and tissue-regenerative capacity, then may offer wound-care in new sustainable applications.

## 4. Challenges in Processing Natural Polymers electrospinning

While natural polymers are advantageous, their electrospinnability is highly sensitive to several factors that include processing parameters such as solvent evaporation rate, solution viscosity, surface tension, and conductivity, which significantly affect the formation of continuous fibers (G. Aguilar-Vázqueza, 2020); (Dara L. Woerdeman, 2007).

**Table 4. Summary of major challenges in electrospinning natural polymers and mitigation strategies**

| **Challenge** | **Description** | **Typical Solution** | **Reference** |
|---|---|---|---|
| Low spinnability | High surface tension and poor chain entanglement | Blend with PVA, PEO, or chitosan | (Woerdeman et al., 2005) |
| Solvent incompatibility | Poor solubility in common solvents | Use formic acid, ethanol-water, or ionic liquids | (Haghi & Akbari, 2007) |
| Protein denaturation | Structural loss during electrospinning | Crosslinking (glutaraldehyde, citric acid) | (Reddy & Yang, 2007) |

From other factors, plant protein conformation or the extent of protein unfolding and chain entanglement in the solvent directly influences fiber morphology and stability (Reddy & Yang, 2007). Thus, blending with synthetic polymers or employing crosslinking methods is sometimes necessary to overcome these challenges and achieve fibers with the desired mechanical and biological properties (Bilginer & Arslan Yildiz, 2020).

## 5. Suitable Materials

### 5.1 Wheat Gluten: A Sustainable Biopolymer for Biomedical and Non-Food Applications

**Wheat gluten, a natural** biopolymer derived from the endosperm of wheat grains, is composed primarily of two major proteins: gliadin and glutenin. These proteins are essential for the unique viscoelastic properties of wheat gluten, which are crucial for shaping the structure and texture of processed wheat-based products. Wheat gluten protein is a widely available, biodegradable, and low-cost biopolymer, making it an attractive material for a variety of applications, including food and bio-based materials production (Reddy & Yang, 2007; Woerdeman et al., 2005) Osborne was the first to classify wheat proteins according to their solubility, identifying the two main fractions: glutenins (alcohol-insoluble) and gliadins (alcohol-soluble) (Shewry et al., 1992). These glutenins and gliadins proteins crosslink through hydrogen bonds and non-covalent interactions to form a viscoelastic gluten mesh that is vital during fermentation and baking (Voci et al., 2021).

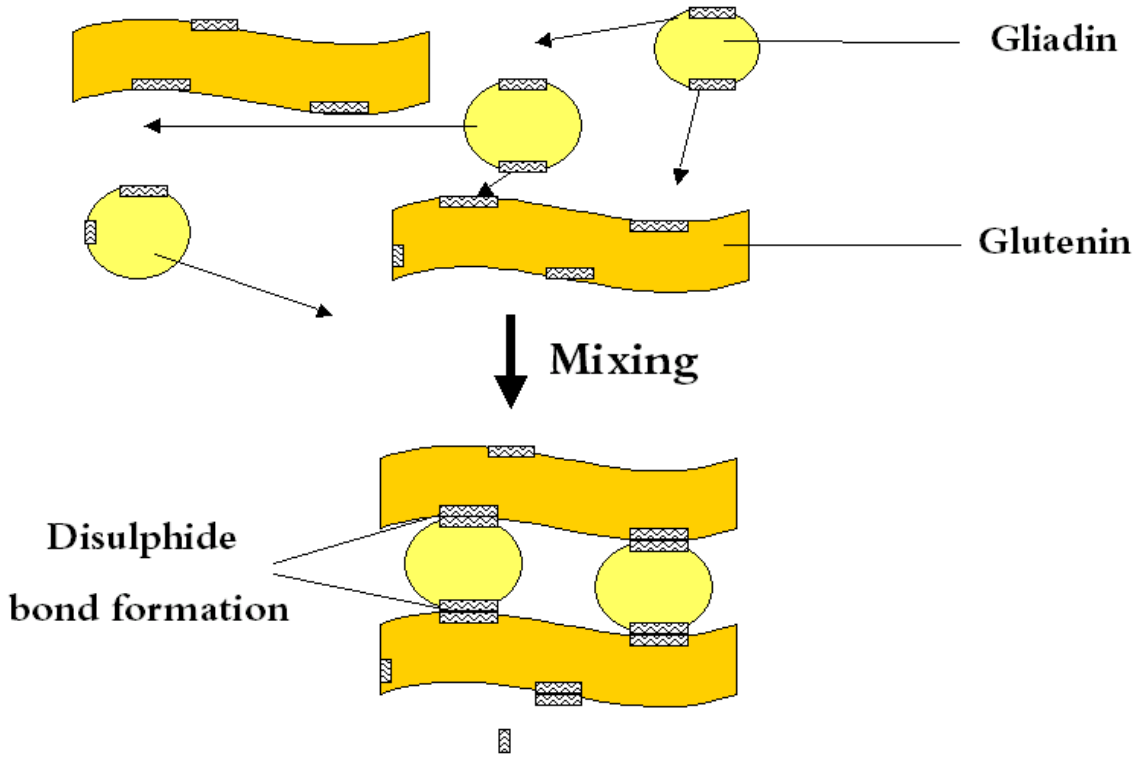


**Figure 9. Structure formation of gluten proteins—gliadins and glutenins—via disulphide bonding. Adapted from Gularte et al. (2007).**

Glutenins are divided into low- and high-molecular weight fractions, while gliadins are monomeric polypeptides, typically ranging from 28 to 70 kDa (Markgren et al., 2020).

**Table 5. Summary of key properties of wheat gluten components.**

| Component | Solubility | Molecular Weight (kDa) | Function in Network | Reference |
|---|---|---|---|---|
| Glutenin (HMW/LMW) | Insoluble in aqueous alcohols (ethanol or isopropanol); soluble only in dilute acid/alkali or in presence of reducing agents (e.g., β-mercaptoethanol) | 80–120 / 30–50 | Provides elasticity | (Shewry & Halford, 2002; Wieser, 2007) |
| Gliadin (α/β, γ, ω) | Soluble in ethanol | 28–70 | Provides viscosity, extensibility | (Y. Zhang et al., 2020) |

Gliadins are divided into three groups based on their electrophoretic mobility: α/β gliadins (28–35 kDa), γ-gliadins (35–40 kDa), and ω-gliadins (55–70 kDa(Y. Zhang et al., 2020). The primary structure of gliadins features a hydrophilic central domain rich in glutamine and proline, surrounded by hydrophobic terminal domains (amino-terminal and carboxyl-terminal domains (H. Zhang et al., 2023). The α/β and γ types of gliadin have large central and carboxyl-terminal domains, while ω-gliadins are dominated by a large central region with small terminal domains. Structural analysis reveals that ω-gliadins are rich in β-turns, while other gliadins predominantly contain α-helices and β-sheets(Wang et al., 2022). The central domain of α-gliadin contains immunogenic fragments like the 33-mer peptide (linked to celiac disease). These structural characteristics highlight the functional complexity of gliadin and its role in various applications, including food production and biomedical materials applications.

In recent years, there has been growing interest in utilizing wheat gluten in non-food applications, especially as a sustainable biopolymer for creating environmentally friendly materials. Wheat gluten's biocompatibility, biodegradability, and adaptability make it an attractive candidate for a variety of applications, particularly in the field of bio-based materials (H. Zhang et al., 2023). One of the most innovative methods for utilizing wheat gluten is electrospinning, a technique that produces nanofibers from polymer solutions. Electrospun wheat gluten nanofibers have shown great promise in a variety of absorbent applications, including their potential development of fibrous materials for blood absorption (Muneer, Hedenqvist, Hall, et al., 2022). The electrospinning process generates continuous fibers with diameters ranging from nanometers to micrometers, and the mechanical properties of these fibers depend on factors such as fiber morphology, diameter, and uniformity, which are influenced by processing parameters and post-processing treatments (B. Zhao et al., 2024). The success of electrospinning is highly dependent on fine-tuning the process parameters, including solution concentration and applied voltage, to ensure uniform fiber morphology (Y. Zhang et al., 2020). Optimizing these parameters is critical

for improving the mechanical strength, thermal stability, and overall performance of the electrospun nanofibers, which are essential for diverse biomedical applications. Biodegradable and biocompatible polymers such as collagen, silk fibroin, zein, and soy protein have been explored for the fabrication of medical devices, including vascular grafts, sutures, and scaffolds for tissue regeneration(Woerdeman et al., 2005). Plant-derived proteins like wheat gluten, which consists mainly of gliadin and glutenin, have recently attracted attention as potential biomaterials due to their film-forming ability and moderate biocompatibility. However, their biomedical use remains largely at the experimental stage, as gluten proteins are known to cause immune responses in sensitive individuals and are therefore unsuitable for direct clinical applications. Nevertheless, preliminary studies indicate that such proteins can form stable matrices capable of encapsulating or immobilizing bioactive compounds, suggesting possible utility in localized or controlled drug delivery under well-defined and biocompatible conditions (Miguel et al., 2018).

For wound healing, modern dressings require specific properties, such as the ability to absorb excess exudates and allow for oxygen permeability. Hydrogels, foams, films, and electrospun nanofibers are commonly used to meet these demands (X. Zhang et al., 2024b). Wheat gluten's high water stability, elasticity, and simple degradability make it an ideal candidate for creating such nanofiber-based materials for wound care and drug deliver(Reddy & Yang, 2007). Wheat gluten's thermoplastic nature allows it to be molded into a variety of forms, offering flexibility in design.

### 5. 2 Gliadin-Based Nanofibers for Biomedical Applications

Gliadin, one of the two major protein fractions of wheat gluten, has been investigated for its potential in electrospinning owing to its amphiphilic nature and relatively good solubility in aqueous ethanol systems. Its high content of proline and glutamine residues provides distinctive molecular flexibility and hydrogen-bonding capability, which facilitate fiber formation and functionalization (Reddy & Yang, 2007). Electrospinning of gliadin yields porous fibrous structures that can mimic aspects of the extracellular matrix (ECM), offering a basis for exploratory studies in tissue scaffolding, wound dressing, and controlled-release (Hajjari et al., 2021; Reddy & Yang, 2007). Nevertheless, gluten-related immunogenicity remains a critical limitation, as gliadins can trigger inflammatory or toxic responses in individuals with celiac disease or gluten sensitivity. Hence, their biomedical use is currently limited to in vitro or non-clinical model applications, where their biocompatibility can still be evaluated under controlled conditions.

The electrospinning process allows for precise control of fiber morphology and porosity, enabling the tuning of mechanical and degradation properties. Gliadin's characteristics can be further adjusted by polymer blending (e.g., with PEO, PVA, or chitosan) or chemical crosslinking, producing composite materials with improved water resistance and mechanical integrity (Bahrami et al., 2023; Hajjari et al., 2021). Crosslinking agents such as glutaraldehyde (GLA) or citric acid (CA) have been shown to enhance the hydrolytic stability of gliadin fibers, with CA offering a safer, bio-based alternative (Y. Li et al., 2021). However, pure gliadin fibers remain highly water-sensitive and mechanically weak compared to collagen- or PLA-based systems, and no studies have yet demonstrated prolonged stability in aqueous or physiological environments extending to several weeks.

Recent studies have explored the chemical modification and blending of gliadin as strategies to create bio-based materials for both food-contact and non-food applications, including controlled release of antioxidants or antimicrobial compounds (X. Zhang et al., 2024b)). While these findings highlight gliadin's potential as a renewable and processable polymeric resource, translating these properties to medical-grade materials requires further investigation into cytotoxicity, immunogenicity, and degradation behavior in biological systems.

In summary, wheat gluten and its components—particularly gliadin—represent promising but still experimental candidates for sustainable biomaterials research. Their biodegradability, film-forming ability, and electrospinnability provide a foundation for developing novel fibrous structures. Nonetheless, their limited aqueous stability and potential allergenicity necessitate cautious evaluation before biomedical or clinical translation. Ongoing research should therefore focus on optimizing composite formulations, green crosslinking methods, and in vitro biocompatibility testing to clarify gliadin's true potential within the broader field of bio-based polymer nanofibers.

### 5.3 Potato Starch: A Sustainable Biopolymer for Electrospinning Applications

Potato starch, a natural biopolymer extracted from the tubers of the Solanum tuberosum plant, has attracted growing interest for its potential in non-food applications, particularly in the development of sustainable and biodegradable materials. As a renewable, low-cost, and eco-friendly polymer, potato starch presents a promising alternative to petroleum-derived synthetic polymers, especially in the fabrication of nanofibers via electrospinning. Electrospun potato starch nanofibers possess desirable features such as high surface area, interconnected porosity, and tunable mechanical properties, making them suitable for diverse biomedical applications, including drug delivery, tissue engineering, and wound healing (Cao et al., 2022; Komur et al., 2017).

Potato starch is composed lof two polysaccharides: amylose, a mostly linear polymer of glucose units, and amylopectin, a highly branched counterpart. Typically, potato starch contains about 25% amylose and 75% amylopectin, a ratio that significantly affects its physicochemical properties such as solubility, viscosity, and gel formation—key parameters in electrospinning (Cao et al., 2022).

**Table 5.2: Effect of amylose/amylopectin ratio on electrospinning and fiber properties.**

| Amylose: Amylopectin Ratio | Fiber Morphology | Electrospinnability | Reference |
|---|---|---|---|
| 1:3 (native starch) | Bead formation | Poor | (Cao et al., 2022) |
| 1:1 (high-amylose corn starch) | Smooth, continuous fibers | Good | (Kong & Ziegler, 2012) |
| 3:1 (engineered starch) | Uniform nanofibers | Excellent | (Cárdenas et al., 2016) |

Electrospinning involves the application of a high-voltage electric field to a polymer solution, generating ultrafine fibers with diameters ranging from nanometers to micrometers. The morphology and mechanical characteristics of the resulting nanofibers are influenced by critical process parameters including polymer concentration, applied voltage, and the distance between the needle and collector (Fonseca et al., 2019).

Due to their biocompatibility, biodegradability, and ability to mimic the extracellular matrix (ECM), electrospun potato starch fibers might be promising for absorbent applications. In wound healing, these nanofibers could support cell adhesion and proliferation, while acting as scaffolds for tissue regeneration (Adeli et al., 2019). Furthermore, these starch fibers use in controlled drug delivery systems, where therapeutic agents are encapsulated within the fibers and gradually released, could be one of attractive research areas.

In wound care, electrospun starch-containing dressings might offer several advantages. Their high water absorbency and flexibility may help to maintain a moist wound environment, which accelerates healing and reduces scarring(X. Zhang et al., 2024b). To enhance the mechanical stability and water resistance of the starch fibers which is critical for usage in absorbent applications, various crosslinking strategies need to be employed. Common crosslinking agents include glutaraldehyde (GLA), citric acid, and natural polysaccharides like genipin, oxidized dextran, and oxidized starch. Crosslinking with GLA has been shown to improve tensile strength and aqueous stability, while citric acid has demonstrated efficacy in enhancing durability and resistance to enzymatic degradation under physiological conditions. Additionally, blending potato starch with other biopolymers such as polyvinyl alcohol (PVA) and chitosan improves mechanical properties, thermal behavior, and bioactivity (Adeli et al., 2019; Cárdenas et al., 2016; Zhang et al., 2024b).

Potato starch has gained increasing attention as a renewable biopolymer for electrospinning due to its film-forming ability, biodegradability, and safety for biomedical use. However, the electrospinning of pure starch remains challenging because of its limited chain flexibility and weak mechanical properties. To address these limitations, researchers have explored starch modification—through chemical derivatization, blending with compatible polymers, or mild crosslinking—to enhance spinnability and stability of the resulting fibers (Fonseca et al., 2019, 2020). Future studies should focus on optimizing formulation parameters and crosslinking strategies to improve the mechanical integrity and aqueous resistance of starch-based nanofibers, thereby enabling their use in selected controlled-release or absorbent applications rather than direct load-bearing biomedical devices.

### 5.4 Designed Potato Starch quality via CRISPR/Cas9

CRISPR-Cas9 genome editing has emerged as a powerful tool in plant biotechnology, enabling precise genetic modifications of specific endogenous genes that were previously difficult to achieve using more traditional approaches such as RNA interference (RNAi) (Ansori et al., 2023). In potato, protocols for CRISPR-Cas9-mediated genome editing have been successfully established, allowing for targeted mutagenesis and trait improvement. Notably, transient expression systems that avoid stable DNA integration offer an advantage for clonally propagated and highly heterozygous crops like potato, where traditional breeding methods are often limited (Qi, 2019).

Potato is a globally important, starch-rich crop with starch primarily composed of branched amylopectin and linear amylose in an approximate 4:1 ratio (Birch et al., 2012) . Increasing the average chain length of amylopectin or enhancing amylose content can yield resistant starch (RS), which offers numerous health benefits such as lowering the glycaemic index (GI), improving gut microbiota composition, and reducing cholesterol and caloric intake (Birch et al., 2012) . Furthermore, long-chain starch characteristics enhance the material properties for bioplastic film production, presenting a sustainable alternative to fossil-based plastics

Research into modifying starch composition in potato has a longstanding history, with amylopectin-only potatoes developed via granule-bound starch synthase (GBSS) suppression using mutagenesis, antisense RNA, RNAi, and recently CRISPR-Cas9. Conversely, high-amylose or structurally altered starch has been achieved by inhibiting or targeting starch branching enzymes (SBEs), with recent advancements enabling precise editing of these genes through CRISPR (Zeeman et al., 2010). However, attempts to produce amylose-only starch in potato have generally led to reduced starch content and impaired plant development, suggesting that a minimal fraction of amylopectin may be necessary for normal physiological function (Lehmann & Robin, 2007) . Interestingly, barley, a cereal crop, was engineered to lack SBEI, SBEIIa, and SBEIIb, and produced amylose-only starch with minimal impact on yield and starch accumulation(Carciofi et al., 2012) .

A recent study by Tuncel et al.(Tuncel et al., 2025) employed CRISPR-Cas9 to target Sbe1 and Sbe2 in potato using both Agrobacterium-mediated transformation and CRISPR-Cas9 editing through PEG-mediated protoplast transfection. While Sbe1 mutants showed little change in starch structure, Sbe2 mutants displayed increased granule numbers, and one double mutant line exhibited dramatically altered starch structure, characterized by reduced branching and longer amylopectin chains. Similar genome editing approaches in rice and sweet potato targeting Sbe2 also led to increased amylose content and modified amylopectin structure, reinforcing the potential of this strategy across species(Tuncel et al., 2025; Tuncel & Qi, 2022) .

Recent advances in CRISPR-Cas9 genome editing have expanded its application beyond crop yield and disease resistance toward modifying starch biosynthesis pathways in plants. For instance, studies in potato have successfully used CRISPR-Cas9 ribonucleoprotein (RNP) complexes to induce targeted mutations in starch-branching enzyme (SBE) genes, producing starches with reduced branching and altered physicochemical properties (X. Zhao et al., 2021). These modified starches exhibit distinctive granule morphology, crystallinity, and digestibility, opening new possibilities for tailoring starch functionality. While such work has primarily focused on food and nutritional aspects, the material potential of starch from CRISPR-modified potatoes remains largely unexplored, particularly regarding their use in biopolymer and nanofiber applications. Exploring these properties could provide a foundation for developing next-generation bio-based functional materials derived from precisely engineered starch structures(Jayarathna et al., 2024).

**5.5 Cellulose**

Cellulose, the most abundant natural polymer on Earth, possesses attractive properties , such as biodegradability, and excellent mechanical strength, making it an ideal candidate for fabricating nanofibers for various applications such as absorbents (Antony Jose et al., 2025). The cellulose can be fabricated into nanofibers through direct its solution electrospinning (Antony Jose et al., 2025). However, several problems do exist such as, the poor solubility of cellulose in most common solvents. To overcome this challenge, a variety of cellulose derivatives and nanocellulose-based composites have been employed as alternatives for electrospinning (Ciechańska, 2004; Kerwald et al., 2022).

Several solvent systems have been investigated for dissolving cellulose, including ionic liquids, N-methylmorpholine-N-oxide (NMMO), LiCl/dimethylacetamide (DMAc), tetra(n-butyl)ammonium hydroxide/dimethyl sulfoxide (TBAH/DMSO), alkali/urea aqueous solutions, and sulphuric acid solutions (Protz et al., 2021). These systems demonstrate that cellulose can be solubilized and processed into nanofibers, although the feasibility of electrospinning strongly depends on the solvent's ability to reduce cellulose aggregation and maintain adequate solution conductivity and viscosity. Among these, LiCl/DMAc is considered one of the most effective systems because it can dissolve cellulose at relatively low temperatures and yields homogeneous solutions suitable for electrospinning (Fang et al., 2025). In contrast, solvents such as concentrated sulphuric acid or alkali/urea systems often lead to cellulose degradation or gelation, while ionic liquids and TBAH/DMSO mixtures, though effective for dissolution, are expensive and difficult to regenerate, limiting their practical use in scalable nanofiber production.

Their approach included a drum-type collector capable of handling high-boiling-point solvents, resulting in uniform nanofibers with diameters ranging from 200 to 550 nm, 76.5% porosity, and a breaking strength of 148.2 cN, with no LiCl residue detected. Similarly, the electrospinning of bacterial cellulose using trifluoroacetic acid (TFA) in combination with poly(vinyl alcohol) (PVA ) has been explored (Jayani et al., 2020). The study found that PVA played a crucial role as a co-solvent, enabling continuous nanofiber formation through enhanced spinnability and hydrogen bonding interactions with bacterial cellulose. The resultant nanofibers displayed a breaking strength of 448 g F, breaking elongation of 10%, a surface area of 4.248 $m^2 g^{-1}$, pore volume of 0.005 $cm^3 g^{-1}$, and average pore diameter of 1.72 nm.

Due to the variability in raw materials and solvent systems, electrospinning parameters must be precisely optimized to ensure successful nanofiber formation. The ongoing development of novel solvent systems and electrospinning configurations continues to expand the potential of cellulose-based nanofibers for advanced material applications(Fang et al., 2025).

### 5.6. Chitosan

Chitosan, a cationic polysaccharide obtained from the partial or complete deacetylation of chitin, can be electrospun into nanofibers owing to its biocompatibility, biodegradability, and intrinsic antimicrobial activity. However, electrospinning pure chitosan is challenging because of its strong intermolecular hydrogen bonding, high solution viscosity, and limited solubility in most organic solvents. As a result, early studies focused on chitosan-based blends or derivatives to improve fiber formation and stability. Blending chitosan with polymers such as poly(ethylene oxide) (PEO), poly(vinyl alcohol) (PVA), or gelatin has been shown to enhance spinnability and produce uniform nanofibers suitable for tissue engineering and wound-healing research (Gadkari

et al., 2019; Geng et al., 2005; Lanno et al., 2020)These composite systems combine the biological functionality of chitosan with the electrospinning stability of the co-polymer, yielding nanofibrous mats that support cell adhesion, proliferation, and antibacterial activity.

To improve the mechanical strength, water stability, and durability of electrospun chitosan nanofibers, various post-treatment and crosslinking approaches have been developed. Common crosslinking agents include glutaraldehyde (GLA), citric acid (CA), and natural crosslinkers such as genipin, oxidized dextran, and oxidized starch. Crosslinking with GLA forms strong covalent bonds between amino groups, substantially enhancing tensile strength and resistance to dissolution in aqueous environments, although residual toxicity limits its biomedical use. Citric acid has emerged as a greener alternative, improving hydrolytic stability and enzymatic resistance under physiological conditions (Adeli et al., 2019). Similarly, genipin, a naturally derived compound from Gardenia jasminoides, offers low-toxicity crosslinking by reacting with amino groups of chitosan, yielding blue-colored, stable networks suitable for cell-culture applications (Sharma et al., 2022)). In addition, mild treatments with tripolyphosphate (TPP) or oxidized polysaccharides can provide ionic or covalent crosslinking, respectively, enhancing the dimensional stability of the fibers without compromising their biocompatibility. These strategies collectively extend the functional use of chitosan-based nanofibers in biomedical and environmental applications, where long-term aqueous stability and mechanical integrity are critical.

Initial attempts to fabricate chitosan-based nanofibers focused on blended systems, often incorporating poly(ethylene glycol or using chitosan derivatives), due to the inherent challenges associated with electrospinning pure chitosan.

**Table 5.3 Effect of solvents and blends on electrospinnability of chitosan.**

| Solvent System | Additive Polymer | Fiber Uniformity | Notes | Reference |
|---|---|---|---|---|
| Acetic acid | None | Poor | High surface tension | (Ohkawa et al., 2004) |
| Acetic acid + PVA | PVA (10–30%) | Excellent | Smooth continuous fibers | (Jia et al., 2007) |
| TFA | None | Moderate | Requires rapid evaporation | (Chen et al., 2007) |

These challenges stem from the strong intermolecular associations within chitosan that hinder its processability. In addition, blended systems of chitosan with poly(vinyl alcohol) (PVA) were also developed to overcome processing limitations. Here, PVA was selected due to its strong hydrogen bonding interactions with chitosan and its known electrospinnability from aqueous media(Jia et al., 2007).

To progress towards a pure chitosan electrospinning system, a range of acidic solvents including dilute hydrochloric acid, acetic acid, formic acid, dichloroacetic acid, and trifluoroacetic acid were investigated for their ability to dissolve chitosan and facilitate electrospinning(Chen et al., 2007; Jia et al., 2007; Ohkawa et al., 2004). These solvents like acetic acid, TFA and formic acid were chosen based on their widespread application in chitosan solution dynamics studies

### 5.7. Cinnamaldehyde

Cinnamaldehyde (CA), also referred to as cinnamic aldehyde, is the principal constituent of cinnamon essential oil, accounting for approximately 85% of its composition, with a purity that can reach up to 98% in refined extracts (Srisa & Harnkarnsujarit, 2020). This aromatic α,β-unsaturated aldehyde has attracted considerable attention due to its wide-ranging biological and pharmacological activities. It has been extensively characterized for its chemical structure and has demonstrated promising properties as an antimicrobial, antioxidant, and anticancer agent. Cinnamaldehyde, as a plant-derived secondary metabolite, exemplifies the bioactivity and chemical diversity of natural products. Such compounds, produced by plants to cope with environmental stressors or pathogenic invasions, often serve as key bioactive agents in essential oils (Stevens & Allred, 2022). Cinnamon essential oil, extracted from different parts of Cinnamomum species (e.g., bark, leaf), is widely studied for its unique aroma and significant antibacterial potential (G. Zhang et al., 2023), (Barrera-Martínez et al., 2024). However, the natural variability in its composition poses challenges for standardizing its bioactivity. Among its constituents, cinnamaldehyde—particularly from Cinnamomum zeylanicum and Cinnamomum cassia—can comprise up to 90% of the oil (Jaramillo Jimenez et al., 2024).

The bioactivities of cinnamaldehyde are diverse, including insecticidal, antibacterial, antifungal, antioxidant, anti-hyperglycemic, and anticancer effects. These multifaceted properties have catalyzed its application in food preservation and biomedicine (Jaramillo Jimenez et al., 2024; Jo et al., 2015; G. Zhang et al., 2023). For instance, (Jaramillo Jimenez et al., 2024)demonstrated the potent antibacterial activity of cinnamaldehyde against multidrug-resistant Acinetobacter baumannii strains, reporting minimum inhibitory concentrations (MICs) as low as 0.01–0.04% (v/v) and synergistic effects with conventional antibiotics. Furthermore, cinnamaldehyde is known to generate reactive oxygen species (ROS), which can promote apoptosis in tumor cells by inducing oxidative stress.

Numerous studies have reported the efficacy of cinnamaldehyde against a broad spectrum of pathogenic microorganisms, including both Gram-positive and Gram-negative bacteria (e.g., Escherichia coli), as well as fungal species such as yeasts and filamentous molds (Xing et al., 2024). This potent antimicrobial activity has positioned cinnamaldehyde as a valuable candidate in the design of biomaterials for wound healing applications. In a recent investigation, antibacterial membranes were fabricated by chemically crosslinking gelatin and chitosan—two biopolymers known for their biocompatibility and biodegradability. Cinnamaldehyde was covalently immobilized within the biopolymer matrix by coupling its aldehyde groups with the free amine ($–NH_2$) groups of gelatin and chitosan, thereby enhancing the antibacterial efficacy of the composite membranes (Kenawy et al., 2019; Sultan et al., 2024). These crosslinked gelatin/chitosan/cinnamaldehyde membranes were thoroughly characterized using various

physicochemical methods and evaluated for their antimicrobial performance against four common wound-infecting bacterial strains. Additionally, the membranes' hemocompatibility and protein adsorption characteristics were assessed to determine their suitability for biomedical use.

Despite having strong antibacterial and antioxidant activity cinnamaldehyde's poor aqueous solubility (approximately 1.1 g/L at 20 °C), susceptibility to degradation under light and air, and potential to cause allergic skin reactions have limited its direct application. To address these limitations, two major strategies have been proposed: (1) encapsulation in polymeric matrices to create “cinnamaldehyde-loaded polymers” that allow controlled or sustained release, and (2) covalent conjugation into polymers to form “cinnamaldehyde-conjugated polymers”.

The comparative overview provided in Table 5.4 summarizes the key natural polymers explored for electrospinning and highlights their respective features, limitations, and biomedical potential. Among these, wheat gluten and gliadin exhibit favorable absorption of biological fluids and ECM-like fibrous morphology, supporting preliminary wound-healing investigations. Potato starch and cellulose offer renewable and mechanically robust alternatives for controlled drug release and structural scaffolds, whereas chitosan provides strong antibacterial activity but remains challenging to spin in pure form. The inclusion of cinnamaldehyde as a bioactive additive further enhances antimicrobial efficacy across these systems. Collectively, these findings underscore the versatility of bio-based polymers in designing sustainable nanofibrous materials, while emphasizing the need for further optimization of solubility, mechanical performance, and long-term biocompatibility before clinical translation.

**Table 5.4: Summary of Biopolymers Used in Electrospinning**

| **Polymer** | **Source** | **Key Features** | **Limitation** | **Biomedical Use potential** | **Reference** |
|---|---|---|---|---|---|
| Wheat gluten | Wheat grain | Elasticity, film-forming | Water sensitivity | good absorbing behavior of bioliquids and blood | (Muneer, Hedenqvist, Hall, et al., 2022; Reddy & Yang, 2007) |
| Gliadin | Wheat gluten | Bioactive, ECM-like | Solvent dependence | Tissue scaffold | (Muneer, Hedenqvist, & Kuktaite, 2022; Reddy & Yang, 2007; Voci et al., 2021) |

| | | | | | |
|---|---|---|---|---|---|
| Potato starch | Tubers | Renewable, tunable | Brittle unless blended | Drug release | (Fonseca et al., 2019) |
| Cellulose | Biomass | Strong, abundant | Poor solubility | Scaffolds | (Fang et al., 2025) |
| Chitosan | Shellfish | Antibacterial, bioactive | Difficult to spin pure | Antimicrobial mats | (Ohkawa et al., 2004) |
| Cinnamaldehyde | Essential oil | Antimicrobial, antioxidant | Volatility | Antibacterial coatings | (Srisa & Harnkarnsujarit, 2020) |

## 6. Relation to on-going Research and Societal Relevance

This review synthesizes current scientific understanding and identifies remaining challenges in the electrospinning of bio-based polymers, particularly proteins and starch-derived systems, for wound healing and biomedical material applications. By highlighting material–structure–function relationships, solvent-system considerations, post-processing strategies, and bioactivity integration, the review aims to position natural polymer nanofibers within the broader context of sustainable and functional wound-care solutions.

The literature demonstrates that bio-based nanofibers offer the potential for improved moisture management, biocompatibility, and localized delivery of functional agents. At the same time, challenges remain in achieving consistent spinnability, aqueous stability, mechanical robustness, and scalable production while maintaining biocompatibility and environmentally responsible processing. The review therefore outlines opportunities for future research focused on green chemistry, structure-guided material design, and improved performance.

### Societal Context

The development of sustainable, bio-based wound-care materials aligns with global public-health and environmental priorities. Chronic and infected wounds represent a significant healthcare burden, and advanced dressings that improve healing outcomes while reducing reliance on systemic antibiotics may contribute to antimicrobial-resistance mitigation. In addition, the valorisation of agricultural side streams and naturally derived materials supports circular-bioeconomy objectives by reducing dependency on fossil-based polymers and promoting resource-efficient innovation.

Future research, industrial translation, and regulatory frameworks will benefit from interdisciplinary collaboration across materials science, biotechnology, healthcare, and sustainability domains**.**

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