Compositional Study of Polymer Blend PVA, Pectin, Sodium Alginate, and Gelatin Electrospun Nanofiber for Wound Dressing Application

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Abstract: Electrospun nanofibers are a biomaterial effective for wound healing due to their high surface area, tunable properties, and resemblance to the extracellular matrix. Nanofibers from the mixture of polymeric materials like gelatin, sodium alginate, pectin, and polyvinyl alcohol (PVA) were investigated in this study. Pectin, sodium alginate, and gelatin are selected for their nature of being applied as tissue carriers, and they have the properties of being biocompatible and biodegradable while inducing cell proliferation. Unfortunately, these polymers have some drawbacks: most of them have poor mechanical strength or poor processing ability through electrospinning. To enhance these properties, PVA was incorporated. The result showed that an optimal blend ratio of 20% PVA, 40% pectin, 25% sodium alginate, and 15% gelatin yielded a fibrous structure with an average diameter of the fibers equal to 174.82 ± 13 nm, surface tension of 33.29 mN/m, and viscosity at 7,378 cP, which facilitated the uniform fiber formation and a porous structure for enhanced gas exchange and moisture retention, significantly aiding wound healing.

Keywords: Nanofibers, polymer blend, electrospinning, wound healing.

1. INTRODUCTION

The skin, being the largest organ, envelops the entirety of the human body's external surface, spanning an approximate area of 2 m^2 [1-3]. Functioning as a vital component of human anatomy, it assumes the crucial roles of shielding individuals from external aggressors, maintaining thermal equilibrium, and detecting external stimuli [4]. However, despite serving as a protective barrier against environmental threats, the skin remains susceptible to both physical and thermal traumas.

Asymmetric membranes have captured the attention of researchers due to their structural resemblance to natural skin. These membranes usually have a dense outer layer that mimics the epidermis, offering protection against physical, chemical, and bacterial threats while managing gas exchanges, including water vapor, oxygen, and carbon dioxide [2]. The inner layer is porous, enabling it to absorb exudates and support cell adhesion and proliferation [5-7]. Moreover, asymmetric membranes can be produced using various techniques such as wet and dry/wet phase inversion, $scCO_2$-assisted phase inversion, electrospinning, and bioprinting [2].

In this research, asymmetric membranes fabricated using electrospinning. The materials chosen for this study include PVA, pectin, sodium alginate, and gelatin. Natural polymers like pectin, sodium alginate, and gelatin are preferred for wound healing due to their affordability, biocompatibility, non-toxicity, and biodegradability. Cui *et al*. (2016) reported that electrospun nanofibers prepared from citrus pectin had an ultimate tensile strength (UTS) of 14.6 ± 5.2 MPa, with an elongation of 192.3 ± 68.7% [8]. Sodium alginate itself had a breaking strength of 23.8 MPa in the work of Lu *et al*. (2020) [9]. Gomes *et al*. (2015) further showed that crosslinked gelatin nanofibers had an ultimate tensile strength (UTS) of 2.2 ± 0.6 MPa and an elongation percentage of 162 ± 96% [10]. However, even with these results, the mechanical properties of these particular polymers are often not sufficient for most high-end applications. Polyvinyl alcohol (PVA) is one of the most common synthetic polymers, and there have been investigations into it as an additive to address these limitations. According to Rajora *et al*. (2023), PVA possesses a Young's modulus of 80.70 ± 2.33% [11]. The approach of blending PVA with natural polymers like pectin, sodium alginate, and gelatin appears to greatly enhance mechanical strength while achieving optimal electrospinning performance in nanofiber matrices. This is in the realization of the complementary properties of PVA and the natural polymers, yielding nanofibers with predetermined mechanical and structural properties for a wide range of applications. Additionally, sodium alginate, similar to extracellular matrices, is biologically inert and lacks sufficient cell adhesion sites. To mitigate this issue, the

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polymer blend combined with gelatin to promote cell adhesion and proliferation. A preliminary study conducted to investigate the morphology and rheological behavior of the membranes.

2. EXPERIMENTAL

2.1. Material and Preparation of Electrospinning Solution

This study used polyvinyl alcohol (PVA), pectin, sodium alginate, and gelatin to fabricate nanofibers through electrospinning. Moreover, glutaraldehyde was adopted as a crosslinking agent to enhance the stability of the polymer blend solution. All the materials were purchased from Emperor Chemical Co., Ltd., Taipei, Taiwan.

The electrospinning solution was prepared by dissolving 12 wt.% PVA, 8 wt.% pectin, 5 wt.% sodium alginate, and 12 wt.%t gelatin in 100 mL of deionized (DI) water. The sodium alginate and gelatin volume ratios were maintained at 25 and 15, respectively. In the present study, the pectin-to-PVA volume ratios were systematically varied in the electrospinning solution to optimize the formulation in producing consistently uniform and regular electrospun nanofibers. The varying compositions of these electrospinning solutions are summarized in Table **1**. These had been carefully selected from preliminary experimental outcomes to confirm their sufficiency and aptness for obtaining the target nanofiber morphology and characteristics. Additionally, 500 mL of 0.5 vol.% of glutaraldehyde was added to each varying composition and mixed by a magnetic stirrer for 30 minutes at 150 rpm.

Table 1: Varying Composition of Electrospinning

PVA:Pectin:SodiumAlginate:Gelatin(vol.%)	10:50:25:15
	20:40:25:15
	30:30:25:15

2.2. Electrospinning Process

Electrospinning was performed using the commercial system (FES-COE, Falco, Taiwan) to fabricate nanofibers. The process parameters were carefully optimized, with the injection pump flow rate set at 0.0059 µL/min, an applied voltage of 12 kV, and a working distance of 9 cm, ensuring consistent and high-quality fiber production.

2.3. Characterization

The morphology and surface properties of the nanofibers were analyzed by a field emission scanning electron microscope (FE-SEM, JEOL 7900F, Japan) under an acceleration voltage of 5 kV at a magnification of 5000×. The diameter of nanofibers was measured using ImageJ software; measurements were taken from 100 randomly selected nanofibers from each sample, after which the average diameter value was computed to ensure the statistical reliability of the measurement. Moreover, the elemental composition of the nanofibers was analyzed by energy-dispersive spectroscopy (EDS, Ultim Max 100, Oxford).

The rheological properties of the electrospinning solutions, such as viscosity and surface tension, have been done systematically. Viscosity measurements were carried out at ambient temperature using a Brookfield DV2T viscometer (AMETEK, USA) and a digital surface tensiometer (BZY-IV, Hengping Instrument Ltd., Shanghai, China) adapted to the Wilhelmy plate method, respectively. To ensure feasible and acceptable results, analysis for every solution was replicated three times, and averages are reflected in the rest of this paper.

3. RESULT AND DISCUSSION

The morphological evolution of the electrospun nanofibers with varying compositions is depicted in Figure **1a-c**. The elemental composition analysis of the nanofibers revealed the presence of carbon (C), oxygen (O), nitrogen (N), and sodium (Na). Additionally, peaks corresponding to platinum (Pt) were observed, which can be attributed to the Pt coating applied to the organic sample to enhance its conductivity during analysis. These images reveal that when the PVA-to-pectin volume ratio was 10:50 obtained in thin fibers, with an average diameter of 94.93 ± 1.6 nm, followed by the formation of numerous irregularly large beads distributed along the fibers. The insolubility of pectin in typical organic solvents is related to the appearance of a considerable amount of irregularly sized beads along the fibers [12, 13]. An aqueous solution of pectin does not produce a stable and consistent jet during the electrospinning process. Therefore, this unstably formed jet could not allow the fibers to form uniformly, and this also promoted the generation of beads that degraded the morphology and integrity of the nanofibers. On the other hand, increasing the PVA-to-pectin volume ratio to 20:40 formed continuous fibers with minimal bead formation,

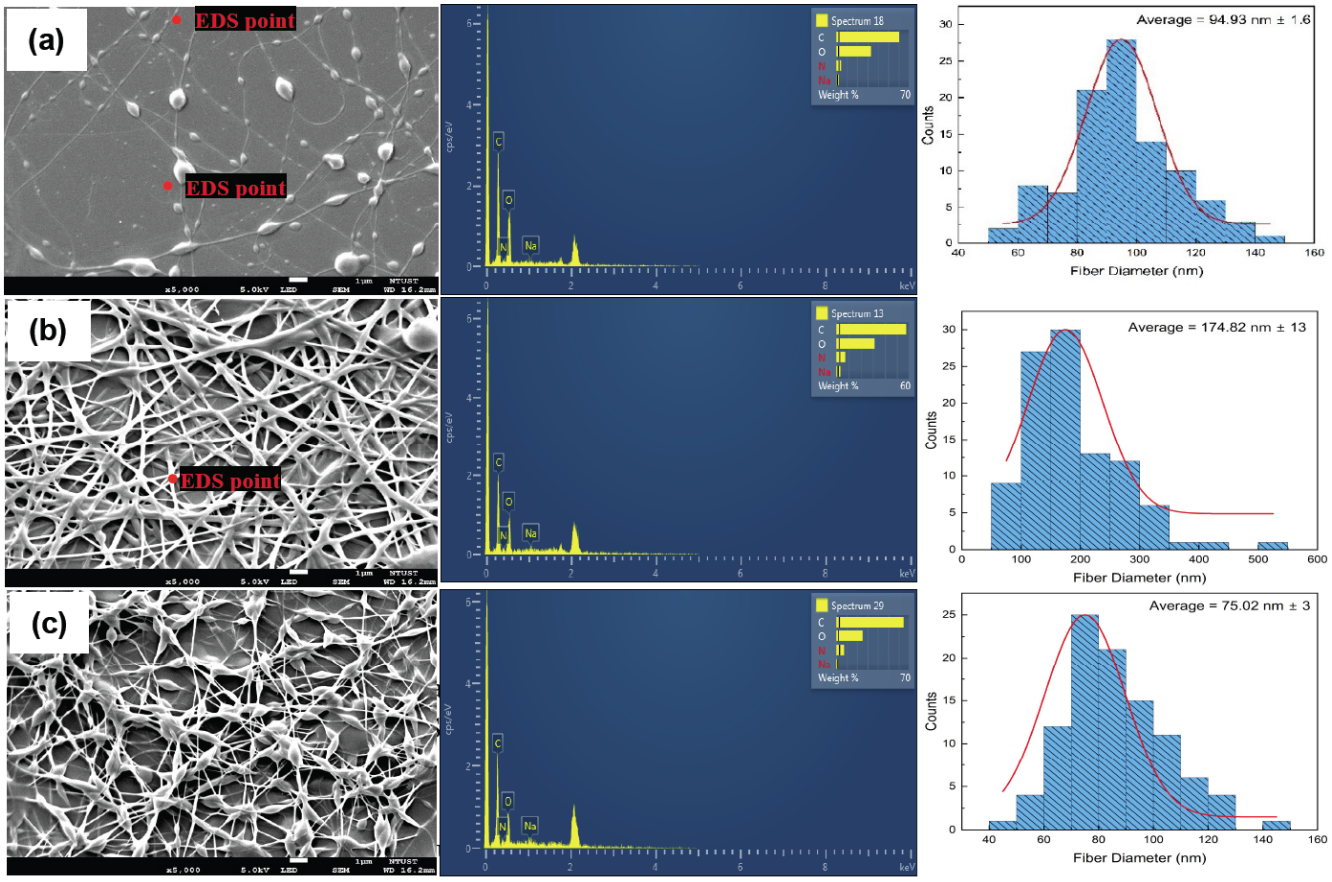

Figure 1: Morphologies and elemental compositions of electrospun nanofibers with varying compositions PVA:Pectin:SodiumAlginate:Gelatin (vol.%) (**a**) 10:50:25:15, (**b**) 20:40:25:15, and (**c**) 30:30:25:15.

achieving an average fiber diameter of 174.82 ± 13 nm. However, when the PVA-to-pectin ratio was increased further to 30:30, finer fibers with beads were densely packed throughout the fiber network, which reduced the average fiber diameter to 75.02 ± 3 nm.

The results were significantly influenced by viscosity, a crucial parameter in the electrospinning process as it directly governs the extent of polymer chain entanglement in solution. As shown in Figure **2a**, the core solution comprising sodium alginate and gelatin, without the addition of PVA and pectin, exhibited a rather high viscosity, which led to needle clogging and prevented the progression of the electrospinning process, thus inhibiting fiber formation [14]. Increasing the PVA-to-pectin volume ratio initially decreased the viscosity up to a ratio of 30:30, beyond which the viscosity began to rise. This trend corresponded with changes in fiber diameter, which increased up to a 20:40 ratio before decreasing. Highly viscous solutions hinder solvent evaporation during the flight from the needle to the collector, adversely affecting fiber formation [15]. In addition to viscosity, surface tension also played a critical role in fiber formation. As shown in Figure **2b**, moderate surface tension of 33.29 mN/m resulted in the optimal fiber diameter (175 nm) at a PVA-to-pectin volume ratio of 20:40. High surface tension, however, caused bead formation along the fibers (Figure **1a**) as the electrostatic forces were insufficient to overcome the surface tension, leading to jet instability and the formation of spherical droplets instead of continuous fibers [16]. Conversely, excessively low surface tension may result in insufficient cohesive force within the solution, leading to the formation of droplets or very thin, unstable fibers.

4. CONCLUSION

In the present work, nanofibers were successfully produced by an electrospinning technique using a polymeric mixture composed of PVA, pectin, sodium alginate, and gelatin. The fibers from the PVA:pectin:sodiumalginate:gelatin formulation in the ratio 20:40:15:25 produced continuous and uniform fibers. This could be accounted for by the favorable solution properties, which had a rather low viscosity of 7,378 cP but a surface tension of 33.29 mN/m that was

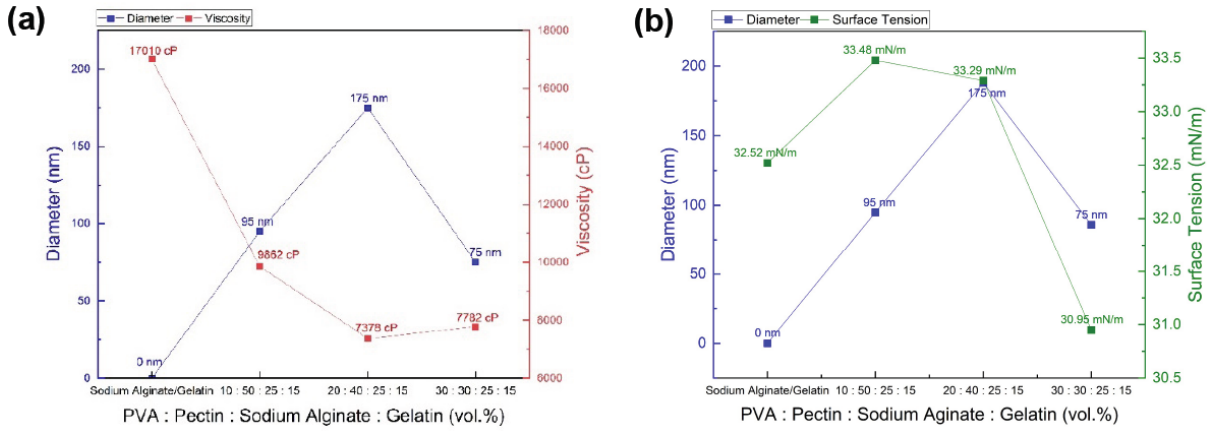

Figure 2: Correlation between (**a**) fiber diameter and viscosity, (**b**) fiber diameter and surface tension for various polymer blend compositions.

moderate; this combination contributed to maintaining the stability of the jet in the course of the electrospinning process.

DECLARATION OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest regarding this study.

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