Fibroin and Polyvinyl Alcohol Hydrogel Wound Dressing Containing Silk Sericin Prepared Using High-Pressure Carbon Dioxide

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Submitted for publication October 25, 2018.
Accepted in revised form December 23, 2018.

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Objective: To fabricate and investigate the properties of fibroin and polyvinyl alcohol (PVA) hydrogels containing sericin prepared using high-pressure carbon dioxide (CO₂).

Approach: In this study, fibroin/PVA hydrogels with and without sericin were prepared using the high-pressure CO₂ method. The physical and mechanical properties of the hydrogels were investigated using field-emission scanning electron microscopy, Fourier-transform infrared spectroscopy, thermogravimetric analysis, and differential scanning calorimetry, and the swelling, water retention, and compressive properties were assessed.

Results: The hydrogels obtained from the combination of fibroin and PVA presented a compositional gradient along the hydrogel thickness and structure. The upper layer of the hydrogel consisted of a fibroin-based hydrogel blended with PVA, whereas the lower layer contained only fibroin. The mechanical properties regarding compression of the fibroin/PVA hydrogel were significantly better than those of the pure fibroin hydrogel, for hydrogels with and without sericin. Moreover, the mechanical properties of the hydrogels with sericin were significantly better than those without sericin. The water contents of all samples were >90%.

Innovation: This study assessed a new combination of a wound healing agent and a biomaterial dressing. Moreover, this hydrogel production technique used a clean method without the need for a chemical crosslinking agent.

Conclusion: The combination of the fibroin and PVA hydrogel and sericin prepared using the high-pressure CO₂ method led to good physical properties. This material may be a candidate for medical applications.

Keywords: hydrogel, fibroin, PVA, high-pressure carbon dioxide method, sericin, dressing

INTRODUCTION

AN IDEAL WOUND dressing should provide a moist, gas-permeable, and protective environment and actively absorb wound exudates. In addition, a wound dressing should be easy to handle, pliable, and cost effective.¹ Hydrogel wound dressings can have

a water content >80%.² Therefore, hydrogels can provide a moist wound environment that is suitable for wound healing. These materials can also promote autolytic debridement to the wound and are nonadherent. Hydrogels are suitable, in particular, for dry and necrotic wounds.³ The

physical properties of hydrogels depend on the pore structure, flexibility, and mechanical strength.⁴ The tight pore structure of a hydrogel can protect the wound from bacterial invasion.⁵ Moreover, it can transfer bioactive molecules such as antibacterial agents and wound healing agents to the wound. Hydrogels can also control diffusion, swelling, and drug release.⁴ Previous studies have demonstrated that the epithelialization rate of hydrogel wound treatments is significantly higher than that with traditional gauze dressings.⁶

Silk cocoon (*Bombyx mori*) filaments consist of two proteins; that is, fibroin forms the structural core (~75%) and is coated with a sericin hydrophilic⁷ matrix (~25%).⁸ The major amino acids of fibroin are glycine (45%) and alanine (29%), whereas the major amino acid of sericin is serine (33%).⁹ Fibroin-based materials have been shown to be able to increase cell viability and differentiation,¹⁰ and to promote phenotype-specific cell metabolism.¹¹ Normally, sericin is added to wound dressings because of its ability to promote wound healing. Sericin can activate fibroblasts to promote collagen type I synthesis.¹² Nagai *et al.* investigated the effect of sericin on the adhesion of a human corneal epithelial cell line (HCE-T).¹³ They studied sericin concentrations at 0.01%, 0.05%, 0.1%, 0.2%, 0.3%, 0.4%, 0.5%, and 1%, and found that 0.2% sericin had the strongest effects with regard to cell adhesion. Therefore, 0.2% sericin was chosen to add to the wound dressing in this study.

Polyvinyl alcohol (PVA) is a biocompatible polymer. It has high polarity and good mechanical properties.¹⁴ PVA is mainly used for the production of binders, emulsifiers, dispersants, glues, and composite materials, including medical devices and wound dressings.^{15,16} Intavisade and Oonkhanond found that PVA may interact with fibroin by decreasing the gelation time of fibroin hydrogels.¹⁷ Moreover, Li *et al.* reported that the strength and elongation of the membrane were improved when the content of PVA in a PVA/fibroin membrane was increased.¹⁸ Accordingly, the addition of PVA or a polymer to fibroin may improve the physical and mechanical properties of fibroin hydrogels.¹⁹

The high-pressure carbon dioxide (CO₂) method is a nonflammable and clean method. It induces fibroin gelation without any need for chemical crosslinking agents. This method directly provides CO₂ gas to a fibroin solution in a closed system. This change in the physicochemical environment results in the sol–gel transition of fibroin and the formation of stable gel networks.²⁰ However, pure fibroin hydrogels prepared using high-pressure CO₂ are not suitable as wound dressings due to

their fragility and poor flexibility. Adding PVA and sericin (as a gumming protein) may improve these properties. In this study, we further improved the dressing properties of fibroin while maintaining the characteristics of dressing as a natural material. Therefore, a low concentration of synthetic material (1% PVA) was used. The objective of this study was to fabricate and investigate the properties of a fibroin/PVA hydrogel containing sericin prepared using high-pressure CO₂.

CLINICAL PROBLEM ADDRESSED

Hydrogels are a popular wound dressing because of their ability to maintain a moist wound environment. However, research and development of hydrogels as a biomedical device and wound healing agent has not seen much success. A new technology that was friendly with the environment was also limited. Therefore, the results of this study could provide new ideas for hydrogel research and development.

MATERIALS AND METHODS

Materials

Silk fibroin and sericin solutions were prepared from *B. mori* cocoons supplied by Chul Thai Silk Co., Ltd. (Petchaboon Province, Thailand). Silk cocoons were cut into small pieces, and treated twice in 0.11% and 0.04% sodium carbonate (Sigma-Aldrich, St. Louis, MO) solutions at 98°C for 1.5 h. Then, the cocoons were rinsed in deionized water (DI water), dried overnight, and dissolved in 9.3M lithium bromide solution (Fluka Chemicals, Buchs, Switzerland) at 65°C for 4 h. Then, the solution was dialyzed for 3 days at room temperature against DI water with regular water changes. Silk sericin solution was prepared using a modified high-temperature and high-pressure degumming method.²¹ In brief, silk cocoons were cut into small pieces and extracted with DI water by autoclaving at 120°C, 1 bar for 45 min. Analytical-grade PVA was obtained from Sigma-Aldrich (Mw 146–186 kDa, >99% hydrolyzed). PVA solution (8%) was prepared by dissolving PVA in DI water at 90°C overnight.

Methods

Preparation of fibroin and PVA composite hydrogels. Three different formulations were considered in this study (formulations F4, F4P1, and F4P1S0.2), prepared by mixing PVA, fibroin, and sericin in different proportions (Table 1). After mixing, all sample solutions were placed in a chemical reactor (BR-300, Berghof Products+

Table 1. Meaning and formulation of samples

Formulation	Final Concentrations of Sample Solutions (%w/v)		
	Fibroin	PVA	Sericin
F4	4	0	0
F4P1	4	1	0
F4P1S0.2	4	1	0.2

PVA, polyvinyl alcohol.

Instruments, Eningen, Germany) filled with high-pressure CO₂ for 16 h to produce hydrated hydrogels. A heating jacket run by a BDL-3000 temperature controller (Berghof) was used to control the temperature of the reactor at 25°C. A high-performance liquid chromatography pump (Model 426; Alltech, Deerfield, IL) was used to control the pressure of the CO₂ gas in the reactor at 60 bars, 25°C. Hydrated hydrogels were used to test the water content and to perform compression tests. Dried hydrogels were used in the field-emission scanning electron microscopy (FE-SEM), Fourier-transform infrared spectroscopy (FTIR), differential scanning calorimetry (DSC), and thermogravimetric analysis (TGA) studies, as well as the swelling test; these were prepared by freezing hydrated hydrogels in liquid nitrogen for 5 min and lyophilizing the material for 48 h. Each sample was prepared triplicate. Three samples in each group were tested by each method.

Field-emission scanning electron microscopy. A morphological evaluation of dried hydrogel cross-sections was performed on samples sputter coated with a thin palladium-platinum layer (Q150T Turbo-Pumped Sputter Coater/Carbon Coater; Quorum Technologies, UK) and observed by FE-SEM (Zeiss Supra 40; Carl Zeiss, Germany) in secondary electron mode. ImageJ software (NIH) was used for the pore size calculation.

Fourier-transform infrared spectroscopy. The chemical–physical properties of the dried hydrogels were evaluated by FTIR. A Spectrum One apparatus (Perkin Elmer, Waltham, MA) working in attenuated total internal reflection mode was used to collect the spectra of the different materials. Four scans for each spectrum were registered in the wavenumber range of 4,000–650 cm^{−1}, with a resolution of 4 cm^{−1}. All spectra were acquired at room temperature and analyzed with OriginPro version 6.0 (Originlab®, MA).

TGA and DSC. TGA and DSC were used to evaluate the thermal behavior of dried samples. TGA was conducted using a Q5000 thermobalance (TA

Instruments, Eschborn, Germany), testing ~6 mg of material in freshly cleaned platinum pans in the temperature range of 30–600°C, at a heating rate of 10°C/min under nitrogen flow (10 mL/min). DSC measurements were conducted using a DSC Q20 apparatus (TA Instruments) at a heating rate of 10°C/min in an inert atmosphere under nitrogen flow (0–300°C).

Water content

The water content of the composite hydrogels was calculated as follows:

$$\text{Water content(\%)} = [(W_h - W_d)/W_h] \times 100,$$

where W_h is the weight of hydrated hydrogels, and W_d is the dry weight after freezing and freeze drying. Triplicate samples were assessed.

Swelling test

Water uptake by the dried hydrogels was measured by immersion in phosphate buffered solution (PBS) with shaking (100 rpm) at 37°C up to 72 h. The swelling ratio was considered at several time points (1, 2, 4, 8, 24, 48, and 72 h) and calculated as follows:

$$\text{Swelling (ratio)} = (W_w - W_b)/W_b,$$

where W_w is the weight of the rehydrated construct at each time point and W_b is the dry weight of the construct before testing. Testing was performed in triplicate.

Compression test

Hydrated hydrogels (18 mm cylindrical diameter and 5 mm thickness) were tested in triplicate under uniaxial compression using a Bose ElectroForce 3200 mechanical tester (TA Instruments, New Castle, DE) equipped with a 50 N load cell at a constant speed of 3 mm/min. The compressive modulus was calculated from the initial slope of stress–strain curve. The mechanical stress at 50% strain was also recorded and used as a measure of hydrogel strength.

Statistical analysis

Statistical analysis of data was performed using SPSS version 17.0 (SPSS Co., Ltd., Bangkok, Thailand). Analysis of variance with statistical significance at $p < 0.05$ was used to compare test groups with the control group. All tests were performed in triplicate.

RESULTS

Characteristics of the hydrogel

The macroscopic appearance of the hydrated hydrogels (F4, F4P1, and F4P1S0.2) is shown in

Figure 1. Macroscopic appearance of (A) sample F4, (B) sample F4P1, and (C) sample F4P1S0.2. PVA, polyvinyl alcohol.

Fig. 1. All samples were cylindrical in shape. The thickness of each sample was ~ 5 mm. The diameter of each sample was ~ 18 mm. Sample F4 was white, soft, and nontransparent material (one layer). The microstructures of dried sample F4 that was assessed by FE-SEM (Fig. 2) were more homogeneous. The pore diameter of the sample was $3.0 \pm 1.1 \mu\text{m}$. Con-

versely, samples F4P1 and F4P1S0.2 showed double layers (upper and lower layers). For the upper layer, samples were soft and transparent. The pore diameters of the dried samples (F4P1 and F4P1S0.2) were $13.3 \pm 3.2 \mu\text{m}$ and $74.7 \pm 12.5 \mu\text{m}$, respectively, and there were fibers inside the pore. For the lower layer, samples were white, soft, and nontransparent. The

Figure 2. FE-SEM images (400 $\times$) of cross-section of upper and lower layers of dried samples F4, F4P1, and F4P1S0.2. FE-SEM, field-emission scanning electron microscopy.

Figure 3. FTIR spectrum of dried samples (I pure PVA; II sample F4P1 (upper layer); III sample F4P1 (lower layer); IV sample F4P1S0.2 (upper layer); V sample F4P1S0.2 (lower layer); VI sample F4; VII pure sericin). FTIR, Fourier-transform infrared spectroscopy.

pore diameters of the samples were $0.9 \pm 0.1 \mu\text{m}$ and $0.6 \pm 0.2 \mu\text{m}$, respectively, but no fibers were found inside the pores. SEM images of triplicate samples are shown in Supplementary Figs. S1–S3.

FTIR of samples

The FTIR curves of all dried hydrogels compared with pure PVA and pure sericin are shown in Fig. 3. The peaks at $3,200\text{--}3,550 \text{ cm}^{-1}$ were characteristic of O-H groups in all samples. These peaks represent water content. The presence of PVA was underlined

by considering three characteristic bands at $2,840\text{--}3,000 \text{ cm}^{-1}$ (C-H groups), $1,085\text{--}1,150 \text{ cm}^{-1}$ (C-O stretching),²² and $830\text{--}833 \text{ cm}^{-1}$ (C-H bending).²³ These peaks were evident in the pure PVA sample, and in the upper layer of samples F4P1 and F4P1S0.2. Protein (fibroin and sericin) conformations were evaluated considering amide I, II, and III. Amide I was identified at $1,600\text{--}1,700 \text{ cm}^{-1}$. Amide II was determined at $1,510\text{--}1,580 \text{ cm}^{-1}$.²⁴ Amide III was observed at $1,200\text{--}1,350 \text{ cm}^{-1}$.²⁵ All of the amide peaks were analyzed from dried samples F4, F4P1, and F4P1S0.2 (upper and lower layers). Accordingly, the main components of dried samples F4P1 and F4P1S0.2 (upper layer) were fibroin and PVA, whereas the main component of dried samples F4P1 and F4P1S0.2 (lower layer) was fibroin. However, the sericin band was close to fibroin, and the sericin band in dried sample F4P1S0.2 (both layers) was not identified separately. Moreover, it was difficult to observe sericin in dried sample F4P1S0.2 because of its limited amount.

TGA

The thermal degradation of the dried hydrogels is shown in Fig. 4A. The 5% weight of all samples lost at $30\text{--}205^\circ\text{C}$ was adsorbed water. Dried sample F4 degraded at $205\text{--}500^\circ\text{C}$, and the maximum peak was observed at 295°C (Fig. 4B). Similar results were obtained for dried samples F4P1 and F4P1S0.2, showing that the decomposition of both samples was separated into two different weight loss ranges. At $205\text{--}255^\circ\text{C}$, 5% weight loss in both samples involved the decomposition of PVA side

Figure 4. (A) TGA thermograms, (B) DTG spectrum of dried samples (■ F4; ▨ F4P1; ▩ F4P1S0.2). DTG, derivative thermogravimetry; TGA, thermogravimetric analysis.

chains with a maximum peak at 238°C. At 255–500°C, 50% weight loss in both samples involved the decomposition of fibroin and PVA, including sericin, with a maximum peak at 295°C (Fig. 4B). The addition of sericin to F4P1S0.2 did not lead to any obvious differences compared with F4P1.

DSC results

The results of the DSC tests were similar to the TGA results (Fig. 5). There was ~5% degradation of the PVA side chains (6.5% loss of dried sample F4P1, 4.1% loss of dried sample F4P1S0.2) at 229°C. The decomposition of fibroin was found at 289°C. An endothermic peak of dried samples F4P1 and F4P1S0.2 also appeared at 288°C. However, each peak of fibroin, PVA, and sericin could not be separately identified because they had similar decomposition temperatures.

Water content

The percentage water content in all hydrogel formulations is reported in Fig. 6. Hydrated sample F4 retained the highest amount of water ($95.2\% \pm 0.1\%$). Moreover, the water content of hydrated sample F4P1S0.2 was significantly higher than that of hydrated sample F4P1 ($94.1\% \pm 0.1\%$ vs. $93.6\% \pm 0.3\%$, respectively; $p < 0.05$).

Swelling

Hydrogel swelling was evaluated up to 72 days of incubation in PBS. Dried sample F4 (pure fibroin) showed the highest swelling ratio at all experimental time points (Fig. 7). The swelling ratio decreased in all samples in which fibroin was blended with PVA. However, the swelling ratio of the hydrogels that contained sericin was not significantly different than that of the composite hydrogels without sericin.

Figure 5. DSC spectra of (A) dried sample F4, (B) dried sample F4P1, (C) dried sample F4P1S0.2, and (D) dried sample PVA. DSC, differential scanning calorimetry.

Figure 6. Water content (%) of hydrated samples F4, F4P1, F4P1S0.2, * $p < 0.05$ significant difference of hydrated sample F4P1, F4P1S0.2 when compared with hydrated sample F4, ** $p < 0.05$ significant difference of hydrated sample F4P1S0.2 when compared with hydrated sample F4P1.

Mechanical properties in compression

Figures 8 and 9 show the results regarding the mechanical properties of the hydrogels. The compressive modulus of hydrated sample F4P1S0.2 was higher than that of hydrated samples F4P1 and F4, indicating higher strength of this hydrogel. Moreover, the stress at 50% strain of hydrated sample F4P1S0.2 was significantly higher than that of hydrated samples F4P1 and F4 (291.7 ± 41.9 kPa, 182.8 ± 23.2 kPa, and 45.6 ± 8.9 kPa, respectively; $p < 0.05$). The stress at 50% strain of hydrated sample F4P1 was also significantly higher than that of hydrated sample F4. Accordingly, PVA and sericin ef-

Figure 8. Compressive modulus (kPa) of hydrated samples F4, F4P1, and F4P1S0.2.

fectively increased the compressive modulus and strength of the fibroin hydrogels.

DISCUSSION

Wound dressings are products that come into direct contact with a wound. The most important property of a dressing is to protect the wound from the outside environment, including infection protection. It should provide a moist environment for the wound to facilitate re-epithelialization, collagen synthesis, and angiogenesis.²⁶ The dressing should allow gas exchange between the wound and the environment. Moreover, it should be non-adherent to the wound, easy to remove, nontoxic, and nonallergenic. Hydrogels can be used to produce occlusive dressings that provide a moist wound environment. These materials are insoluble hydrophilic materials that contain a high water content (70–90%).¹ Hydrogels are produced by crosslinking of one or more monomers,²⁷ including PVA. PVA is a biodegradable and biocompatible synthetic polymer.²⁸ It is used as a hydrophilic material in biomedical applications. Fibroin and sericin are the major components in silk cocoons. Fibroin has a positive effect on cell adhesion and differentiation.¹⁰ Sericin can activate fibroblasts to promote collagen type I production, which is an important factor in wound healing. Fibroin and sericin are used in tissue engineering and as wound dressing materials.

In this study, fibroin-based hydrogels were fabricated from aqueous solutions using the high-pressure CO₂ method. PVA and sericin were added to the fibroin hydrogel to improve its mechanical and biological properties. Samples obtained after adding PVA to fibroin showed a two-layer structure after gelation (Fig. 1), probably due to phase

Figure 7. Swelling ratio of dried samples (■ sample F4; ▨ sample F4P1; and ▩ sample F4P1S0.2), * $p < 0.05$ significant difference of dried samples F4P1 and F4P1S0.2 when compared with dried sample F4.

Figure 9. Compressive stress–strain of hydrated samples (I) F4, (II) F4P1, and (III) F4P1S0.2. The inset shows the region for determining the compressive modulus of the samples.

separation between the two components during preparation. Tsukada *et al.* have already reported on the immiscibility of fibroin and PVA in blended films.²⁹ The upper layer contained fibroin and PVA (Fig. 1). Phase separation was assessed by SEM images (Fig. 2) and confirmed by FTIR spectra (Fig. 3); it can be seen that the major components of the upper layer of the fibroin/PVA hydrogel with and without sericin were fibroin and PVA. The major component of the lower layer was fibroin. However, sericin peaks were difficult to identify since the amide I, II, and III peaks of sericin were close to those of fibroin^{30–32} and the amount of sericin in the hydrogel was 20 times lower than that of fibroin (4% fibroin/0.2% sericin). However, the sericin concentration in formulation III was ~ 2 mg/mL, considering that just ~ 8 μ g/mL can activate fibroblasts to promote collagen synthesis.²¹

The TGA and derivative thermogravimetry (DTG) thermograms (Fig. 4) show that the polymer chain of PVA in the combination fibroin/PVA hydrogels decomposed at 238°C. These results agree with those of Chahal *et al.*, showing that the decomposition of PVA side chains occurs at ~ 210 – 400 °C.³³ The major weight loss of all samples in this study occurred at ~ 295 °C, but the specific peak of each composition could not be clarified. The temperatures at which weight loss occurs due to fibroin, PVA, and sericin decomposition are all ~ 200 – 400 °C. Gohil *et al.* and other previous studies have reported that the maximum degradation of PVA occurs at ~ 250 – 350 °C.^{22,29} Fibroin undergoes weight loss at ~ 250 – 400 °C.^{29,34} The weight loss pattern of sericin has been detected in a wide temperature range starting

at 220°C.^{35,36} The DSC results in this study (Fig. 5) also agree with TGA results, in that the decomposition of PVA (5%) was observed at 229°C and the decomposition of the pure fibroin and combined fibroin/PVA hydrogels occurred at ~ 289 °C. These results are similar to those obtained in studies by Hassan and Peppas and Bhattacharjee *et al.* Hassan and Peppas reported that the melting peak of PVA is at ~ 229 °C.³⁷ Bhattacharjee *et al.* found that the melting endotherm of pure fibroin is at 250–350°C, with the main peak at 289°C.³⁸ Moreover, Tsukada *et al.* showed that the endotherms observed at 290°C be attributed to the thermal decomposition of the fibroin component in fibroin/PVA blends.²⁹ Furthermore, an amino acid analysis was performed in this study (data not shown). It was found that the amino acid composition of the hydrogel after 3 days of release was similar to that of the hydrogel before release.

For wound dressings, the hydrogel should possess a high water content with excellent strength and flexibility. In this study, the pore sizes of the fibroin and PVA combination (upper layer) were larger than that of pure fibroin, but fibers were observed in the pores. Fibers inside the pores were also reported in a fibroin and PVA blend scaffold in a previous study.²³ In the combination fibroin/PVA hydrogel, PVA was mixed with fibroin. PVA interleaved between the fibroin structures, so the fibroin was prevented from creating a tight structure. The pore sizes of the upper layer that contained fibroin were larger than those observed in the pure fibroin hydrogel. Moreover, the pore sizes in the fibroin/PVA/sericin combination (upper layer) were the

largest; sericin has a more hydrophilic structure, and inserted itself between the fibroin and PVA structure. Nevertheless, in the lower layer, the pore sizes of the fibroin/PVA/sericin hydrogel were smaller than those in the fibroin/PVA hydrogel and pure fibroin hydrogel. The main component of the lower part was fibroin. Therefore, the pore structures were smaller and tighter than those in the upper part.

Regarding the physical properties, the results show that sample F4 has the best water content and swelling properties (Figs. 6 and 7). Sample F4P1 had the poorest water content and swelling properties. These results may correlate with the pore size of the hydrogels. Sample F4 contained homogeneously large pores, so it could hold a larger amount of water. The pore sizes of the fibroin and PVA hydrogels with and without sericin were heterogeneous. They contained larger pores in the upper layer and very small pores in the lower layer. This heterogeneous pore size affects the water content. The upper layer of the fibroin and PVA hydrogels with sericin contained larger pores than the fibroin and PVA hydrogels without sericin, so it could hold a larger amount of water. However, the swelling ratios of all samples were >6 times the dried weight, and the water content of all samples was >90%.

Regarding the mechanical properties, hydrated sample F4 had the lowest compressive modulus, low strength, and poor flexibility. PVA is a hydrophilic polymer that can improve the properties of hydrogels. The combination of fibroin and PVA improved the mechanical properties. As shown in Figs. 8 and 9, the flexibility and strength of the composite fibroin and PVA hydrogel were better than those of the hydrogel without PVA. Oliveira *et al.* found that increasing the amount of PVA in foams could improve the compressive strength.³⁹ The compressive modulus and mechanical strength are also improved when a higher percentage of PVA is added to the hydrogel.⁴⁰ Adding sericin to the hydrogel improved flexibility and strength. A previous study also found that the compressive modulus and mechanical strength of a sericin scaffold are better than those of a scaffold without sericin.⁴¹ Moreover, a higher protein concentration may induce a higher degree of crosslinking between proteins after high-pressure CO₂ treatment.²⁰

INNOVATION

This study developed a fibroin/PVA hydrogel wound dressing containing silk sericin that pro-

KEY FINDINGS

- The structures of the combination of fibroin and PVA hydrogel with sericin and without sericin using the high-pressure CO₂ method were divided into two layers. The components of the upper layer were mostly fibroin and PVA. The main component of the lower layer was fibroin.
- Adding PVA and sericin improved the mechanical properties of the hydrogel.
- The swelling ratio of all samples was greater than 6 times its dried weight, and the water contents of all samples were >90%.
- The fibroin and PVA hydrogel wound dressing containing silk sericin was developed to be a new hydrogel that can provide properties including a moist wound environment and might be a candidate for medical applications.

vides a new combination of wound healing agents in a biomaterial dressing. The properties of this hydrogel were characterized. The results show that this hydrogel might be a candidate for a novel medical device or medical dressing. Moreover, hydrogel production using the high-pressure CO₂ method was a clean method without the need for a chemical crosslinking agent, which provides benefits to consumers and the environment. This study could support future research and development in the field of medical application.

ACKNOWLEDGMENTS AND FUNDING SOURCES

This research is supported by Ratchadapisek Somphot Fund for Postdoctoral Fellowship, Chulalongkorn University to S.N.

AUTHOR DISCLOSURE AND GHOSTWRITING

No competing financial interests exist. The content of this article was expressly written by the authors listed. No ghostwriters were used to write this article.

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SUPPLEMENTARY MATERIAL

Supplementary Figure S1

Supplementary Figure S2

Supplementary Figure S3

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Abbreviations and Acronyms

CO ₂	= carbon dioxide
DI	= deionized
DSC	= differential scanning calorimetry
FE-SEM	= field-emission scanning electron microscopy
FTIR	= Fourier-transform infrared spectroscopy
PVA	= polyvinyl alcohol
TGA	= thermogravimetric analysis