

Erika Adomavičiūtė,
Sigitas Stanys,
*Modestas Žilius,
*Vitalis Briedis

Formation and Analysis of Electrospun Nonwoven Mats from Bicomponent PVA/Aqueous Propolis Nano-Microfibres

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Kaunas University of Technology,
Faculty of Mechanical Engineering and Design,
Department of Materials Engineering,
Studentu 56, LT-51424, Kaunas, Lithuania
E-mail: erika.adomaviciute@ktu.lt

*Lithuanian University of Health Sciences,
Faculty of Pharmacy,
Department of Clinical Pharmacy,
Eiveniu 4, LT-50161, Kaunas, Lithuania

Abstract

Nowadays targeted drug delivery is one of the areas widely investigated in the biomedical application of modern technologies. Propolis is well known natural material because of its confirmed antimicrobial and anti-inflammatory activity, and for these reasons it could be considered as a candidate in developing wound healing textile materials. Electrospun bicomponent mats of poly(vinyl alcohol) (PVA) and aqueous propolis solution were manufactured and analysed in this study. It was observed that the concentration of phenolic acids in aqueous propolis solution or the amount of aqueous propolis in the electrospinning solution had no significant influence on the structure of electrospun mats. From bicomponent PVA/aqueous propolis solutions fewer nanofibres with a diameter of up to 100 nm were electrospun, nor from PVA solution containing no added substances. Analysis of phenolic compound release kinetics demonstrated that up to 86 - 96% of vanilic acid, caffeic acid, vanillin acid, *p*-coumaric acid and ferulic acid had been released from the electrospun PVA/aqueous propolis solution mats in 15 min. It was concluded that electrospun mats from bicomponent PVA/aqueous propolis nano-microfibres may be considered for developing a drug delivery system for local application.

Key words: electrospinning, nano-microfibres, propolis, phenolic compounds.

Introduction

The manufacturing technique most commonly associated with polymeric nanofibres is electrospinning, which is fundamentally different from conventional fibre production techniques and is based on electrostatic forces. In electrospinning, a polymer is dissolved in a solvent (polymer melts can also be used) and generally placed in a glass capillarity. A high voltage is applied between the polymer solution and collector or target at the near end of the capillarity. When the voltage is applied to the polymer solution, the electric force results in the formation of a jet of polymer solution flowing out from the droplet tip to be drawn toward the grounded collector [1].

Electrospun nonwoven mats have a high surface area, small pore size, and high porosity. Due to these characteristics it could be applied in protective clothing, filter media, absorbent material, scaffolds in tissue engineering, nanosensors, wound dressing, drug delivery systems, enzyme immobilisation etc. [1 - 4]. A wide range of polymers could be used in the production of mats by electrospinning. Electrospun nanofibres have been formed from synthetic polymers, natural polymers or a blend of both, including proteins, nucleic acids and even polysaccharides [5].

Electrospun polymeric nanofibres are used in the controlled release of proteins,

drugs and wound healing due to their non-toxicity and high surface area to volume ratio. Different approaches could be applied in the preparation of electrospun polymer for drug delivery:

- drugs are attached onto the surface of the nanofibrous carriers as fine particles;
- both drugs and carriers are electrospinnable, resulting in two types of nanofibres;
- a mixture of drugs and carriers is integrated into a single type of composite nanofibres in different forms, e.g., drugs coated with a carrier, or mixed and/or entangled evenly at a molecular level because of good compatibility.

In the first two cases problems related to burst release usually appear, and hence mostly the latter method is used [6]. A significant amount of data published analyse the possibility of using electrospun nonwoven materials for controlled release of biologically active substances, including antibiotics, anticancer drugs, proteins and DNA, RNA [4, 7].

U.E. Illangakoon et al. [8] fabricated electrospun polyvinylpyrrolidone (PVP) fibres with paracetamol and caffeine. The properties of fibre mats were found to be highly appropriate for the preparation of oral fast dissolving films. K. Kim with co-authors [9] stated that medicated pol(lactide-co-glycolide (PLGA) - based electrospun nonwoven material could be

applied for the prevention of *in vivo* post-surgical adhesions and infections. Biodegradable PLGA-based nanofibrous scaffolds containing a hydrophilic antibiotic drug (cefoxitin sodium) were fabricated via the electrospinning process. P. Karuppuswamy with co-authors [10] manufactured polycaprolactone (PCL) nanofibres with different concentrations of the antibiotic drug tetracycline hydrochloride (TC). The incorporation of TC modifies the PCL membrane surface, increases the fibre diameter, as well as changes the tensile strength and strain and porosity of the PCL membrane. Antibiotic ciprofloxacin [11] was loaded with electrospun PVA and sodium alginate (NaAlg) electrospun composite fibres. Incorporation of the drug analysed also causes an increase in PVA or PVA-NaAlg nanofibre diameter. Cellulose acetate (CA) nanofibrous nonwoven material containing curcumin from the plant *Curcuma longa L*, widely known for its anti-tumor, antioxidant and anti-inflammatory properties, were produced by electrospinning. The fibres obtained were smooth, with no curcumin aggregates observed on the surface of nanofibres. The cytotoxicity of this material was investigated and results demonstrated the absence of toxic effects on human dermal fibroblasts. Thus its suitability for the production of wound dressings was concluded [12].

The electrospinning process was applied for the production of PVA nonwoven

material with antibacterial iodine [13]. C. Kriegel with co-authors [14] produced electrospun antimicrobial nanofibres using solubilised antimicrobial essential oil eugenol in surfactant micelles forming eugenol-containing microemulsions. The microemulsions were mixed with nonionic synthetic polymer (poly(vinyl alcohol - PVA).

Targeted and controlled delivery of anticancer drugs is considered to be of continuously growing interest [7]. The incorporation of anticancer drugs BCNU (1,3-bis(2-chloroethyl)-1-nitrosourea), titanocene dichloride, doxorubicin hydrochloride and paclitaxel into electrospun mats of PEG-PLLA, PLLA, and hyaluronic acid, respectively have been evaluated by different research groups [15 - 18].

Propolis is a resinous substance collected by honeybees from various plants, and is well known because of its confirmed antimicrobial and anti-inflammatory activity. The latter properties of propolis products stimulates scientific research, including the development of innovative propolis products and their new applications. The antimicrobial and anti-inflammatory effects of propolis products are mainly related to the presence of flavonoids, flavones, phenolic acids and their derivatives. The antioxidant activity of propolis is mainly defined by the profile of phenolic compounds present in the product: kaempferol, galangin, caffeates, and free phenolic acids. Propolis collected in Lithuania can be identified by dominating ferulic and coumaric phenolic acids that could be considered as specific quality indicators for propolis raw material and preparations containing propolis [19]. Propolis is one of the most potent natural antibiotics characterized by a very wide spectrum of effects. The preparation of ethanol-free propolis solutions offers a broader application in medicine. The bioactivity of propolis aqueous extracts has been evaluated by multiple researchers [20 - 25], and their results give reliable proof of the presence of multiple biological activity mechanisms of this propolis product. Phytochemical analysis of aqueous and ethanolic extracts of propolis confirmed the presence of different polyphenols, flavonoids and phenylcarboxylic acids as major constituents. Some studies [24] demonstrated higher antioxidative and inhibitory activities of water-soluble extracts of propolis as compared to ethanolic extract. Results obtained from testing ethanolic and aqueous extracts of

the natural compound propolis indicated comparable substantial anti-inflammatory functions as well as antibiotic activities *in vitro* and *in vivo*, and the inhibitory activity of the aqueous extract of propolis on the enzyme dihydrofolate reductase has been confirmed [25]. Data published demonstrate antioxidant and antiradical activities of the lyophilised aqueous extract of propolis originating from east Turkey [26]. Indian propolis aqueous extracts contained higher amounts of phenolic compounds if compared to ethanolic extracts, and have demonstrated stronger antioxidant activity [27]. Drago et al. [28] determined the bacteriostatic activity of aqueous propolis (Actichelated®) to increase the following: *Escherichia coli*, *Pseudomonas aeruginosa* (G-bacteria) < *Proteus mirabilis* (G-), *Staphylococcus aureus* (G+ bacteria) < *Haemophilus influenzae* (G-), *Enterococcus* strains (G+) < *Streptococcus pyogenes* (G+), where the bactericidal effect was stronger against *Staphylococcus aureus* and *Haemophilus influenzae*. This aqueous propolis solution also demonstrated antiviral activity against the flu virus, *Herpes simplex* virus type 1, the parainfluenza virus, and the adenovirus. Stronger antibacterial and antiviral activities were determined if compared to hydroalcoholic propolis extracts [28]. Anti-inflammatory activity was determined for aqueous propolis extracts by suppressing prostaglandin E₂ and IL-6 quantity increase, and by limiting nitric oxide activity. The increase in leucocyte and neutrophil numbers was suppressed by aqueous propolis extracts [29]. An aqueous spray containing Actichelated® propolis solution demonstrated strong local anti-inflammatory activity, and can be applied for treatment of inflammations of mucous membranes due to lower irritation potential comparing to hydroalcoholic and hydroglycerol propolis preparations [30]. The antiproliferative activity of aqueous Turkish propolis extracts was determined by testing on prostate cancer lines (PC-3), which was related to the antioxidant activity of the extract [31].

Propolis has confirmed antibiotic activity, thus it was attempted to incorporate it into polymer solutions and to form electrospun fibres. C. Asawahame et al. [32] electrospun mouth-dissolving polyvinylpyrrolidone (PVP) fibres with ethanol propolis. Propolis/polyurethane electrospun fibres were produced from a mixture of tetrahydrofuran (THF) and N,N dimethylformamide (DMF) solvents [33].

The presence of compounds with different physical and- chemical characteristics make propolis products attractive for use as a model mixture of naturally occurring substances in the experimental development of drug delivery systems. Available scientific data demonstrate potent antioxidant activity, anticancer or anticarcinogenic/antimutagenic, antiatherosclerotic, antibacterial, antiviral, and anti-inflammatory effects of phenolic compounds in propolis products [34]. No data were published regarding attempts to form fibres with aqueous propolis, though the bioactive properties of aqueous propolis solutions have been widely investigated [20 - 31]. Data on the contents of phenolic compounds in fibres that could be considered as indicators of potential product bioactivity have not been published till now.

In this study, bi-component fast dissolving PVA/aqueous propolis nonwoven mats were produced by electrospinning technique, and their quality was evaluated by determining the structure of electrospun mats and release kinetics of phenolic compounds from the mats.

Materials

Polymer of poly(vinyl alcohol) - PVA (Aldrich Chemistry, Germany) $M = 61,000$ g/mol was used.

Raw propolis was obtained from JSC Medicata Filia (Vilnius, Lithuania), and the acetonitrile (Chromasolv) was gradient grade for HPLC, $\geq 99.9\%$ and acetic acid (glacial), $\geq 99.8\%$ pure quality (Sigma-Aldrich Chemie GmbH, Steinheim, Germany). The standards of phenolic compounds for HPLC were purchased from Sigma-Aldrich Chemie GmbH (Steinheim, Germany): vanillic acid ($\geq 98\%$), caffeic acid ($\geq 98\%$), vanillin ($\geq 99\%$), coumaric acid ($\geq 98\%$), and ferulic acid ($\geq 99\%$). Purified water for the preparation of solvents was filtered through a Millipore HPLC grade water preparation cartridge (Millipore, Bedford, PA, USA).

Standardisation of aqueous propolis extract

Propolis aqueous extracts (PAE) were standardised against the total contents of phenolic acids. The PAE of three different concentrations of phenolic acids (PAE 1 = 0.8 mg/ml, PAE 2 = 1.3 mg/ml, and PAE 3 = 2.2 mg/ml) were used in the

manufacturing of a nonwoven mat from nano-microfibres by electrospinning.

Methods

Preparation of polymer solutions

Propolis aqueous extracts (PAE) were produced by the extraction of crude propolis with water (1:10, w/v) and successive dilution to obtain the intended content of total phenolic acids. The extraction procedure was carried out at 70 °C for 1 hour under stirring using a hotplate magnetic stirrer IKAMAG C-MAG HS7 (IKA-Werke GmbH & Co. KG, Staufen, Germany). The propolis aqueous extract was cooled to room temperature and filtered.

Determination of phenolic acids in Propolis Aqueous Extract by HPLC

The PAE was characterised by the determination of the four main phenolic acids (coumaric, ferulic, caffeic and vanillic acids) and vanillin using the Agilent 1260 Infinity capillary LC system (Agilent Technologies, Inc., Santa Clara, CA, USA) with an Agilent diode array detector (DAD) and applying a validated HPLC method for quantification of the above-mentioned phenolic compounds. The separation of phenolic acids and vanillin was performed on an ACE C18 column (150 × 0.5 mm, 5 µm particle size), with the mobile phase containing acetonitrile (solvent A) and 0.5% (v/v) acetic acid in water (solvent B). A linear elution gradient from 1 to 21% of solvent A in B 25 min was applied. The volume of injection was 0.2 µl, the flow rate 20 µl/min, and the column temperature was 25 °C. The identification of phenolic acids was confirmed by UV spectra of the appropriate standards in the wavelength range of 210 – 600 nm. The integration of phenolic acids peaks was performed at 290 nm.

All samples of propolis aqueous extracts were filtered through 0.20 µm sterile nylon membrane filters (diameter of 25 mm) for syringes (Sartorius Stedim Biotech GmbH, Goettingen, Germany) prior to HPLC analysis.

PVA solution of 24% concentration was prepared by dissolving PVA granules in 70 - 80 °C distilled water by magnetic stirring for a few hours. Before the electrospinning process, distilled water and/or PAE (PAE1, PAE2, PAE3) was added to the PVA (C = 24%) solution. Four types

of solutions were evaluated: (i) PVA/H₂O (50% (C = 24%)/50%), (ii) PVA/PAE (50%/50%), (iii) PVA/H₂O/PAE (50%/20%/30%) & (iv) PVA/H₂O/PAE (50%/40%/10%) for their suitability in the production of nano-microfibres. In all electrospun solutions the concentration of PVA polymer was 12%.

The viscosity of electrospun solutions was measured by a viscosimeter –DV II+Pro (Brookfield Engineering Laboratories, Inc., US).

Electrospinning equipment

The substratum material (spunbond from PP filaments) was covered by a layer of nano-microfibres using a “Nanospider™” (Elmarco, Czech Republic) (Figure 1) [13]. A nonwoven mat from nano-microfibres was formed at an applied voltage of 65 kV, distance between electrodes 13 cm, temperature of the electrospinning environment $t = 20 \pm 2$ °C, and air humidity $\gamma = 46 \pm 4$ %.

Characterisation techniques

The structure of electrospun nonwoven mats was determined using a scanning electron microscope - (SEM) FEI Quanta -200 FEG (Netherlands). The diameter of nano-microfibres was measured using the image analysis system LUCIA 5.0. From every sample 200 nano-microfibres from three SEM images (scale 5 µm, magnification ×20000) were measured.

In vitro release study of phenolic acids from electrospun nonwoven mats

In vitro release experiments were performed (n = 2) by testing the dissolution of PAE containing nano-microfibres. Approximately 20 mg of PVA nanofibres (precise amount) was dissolved in 5 ml of purified water while maintaining the temperature at 32 ± 0.1 °C. Samples of 1 ml were removed from the receptor solution at 0.25, 0.5, 1, 2, 4 hours and replaced with the same volume of fresh receptor solution. All samples were filtered

Table 1. Viscosity of electrospun solutions (concentration of phenolic acids in PAE - PAE 1 - 2.2 mg/ml, PAE 2 - 1.3 mg/ml, PAE 3 - 0.8 mg/ml).

Notation of electrospun solution content PVA/PAE	Content of electrospun solutions	PVA/PAE1 $\eta \pm \Delta$, mPa·s	PVA/PAE2 $\eta \pm \Delta$, mPa·s	PVA/PAE3 $\eta \pm \Delta$, mPa·s
100/0	50% PVA (C=24%)/50% H ₂ O	504 ± 60	504 ± 60	504 ± 60
50/50	50% PVA (C=24%)/50% PAE	520 ± 34	570 ± 70	520 ± 35
70/30	50% PVA(C=24%)/20% H ₂ O/30% PAE	520 ± 30	520 ± 60	450 ± 35
90/10	50% PVA(C=24%)/ 40% H ₂ O/ 10% PAE	580 ± 60	570 ± 70	500 ± 90

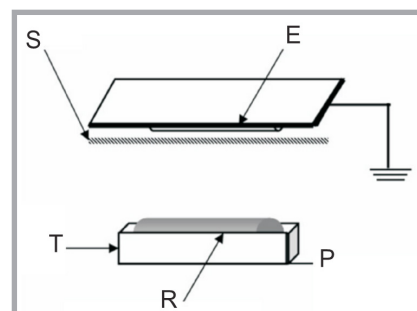


Figure 1. Principal scheme of electrospinning equipment – Nanospider™ (Elmarco): E - grounded electrode, S - support material (spunbond from PP filaments), T - tray with polymer solution, P - power supply with positive polarity 0 - 75 kV, R - rotating electrode (plain cylinder or electrode with tines) [13].

through a nylon membrane filter and analysed by the validated HPLC method.

The quantities of phenolic acids released were evaluated by comparing them to theoretically calculated quantities of phenolic acids in the mats produced while considering the composition of the respective PVA /PAE solution.

Results and discussion

Characteristics indicating electrospun mat quality were analysed in this study: (i) the influence of the concentration of phenolic acids in aqueous propolis: PAE1 - 2.2 mg/ml, PAE2 - 1.3 mg/ml & PAE3 - 0.8 mg/ml on the structure of electrospun nonwoven mats, and (ii) the effect of the PAE amount in bi-component PVA/PAE solutions (90/10, 70/30, and 50/50) on the structure of the electrospun mats.

The viscosity of electrospun solutions is presented in Table 1. In all electrospun solutions the concentration of PVA polymer was kept at 12%, and consequently there is no significant difference between the viscosity of electrospun solutions.

The addition of PAE had no significant effect on the structure of electrospun

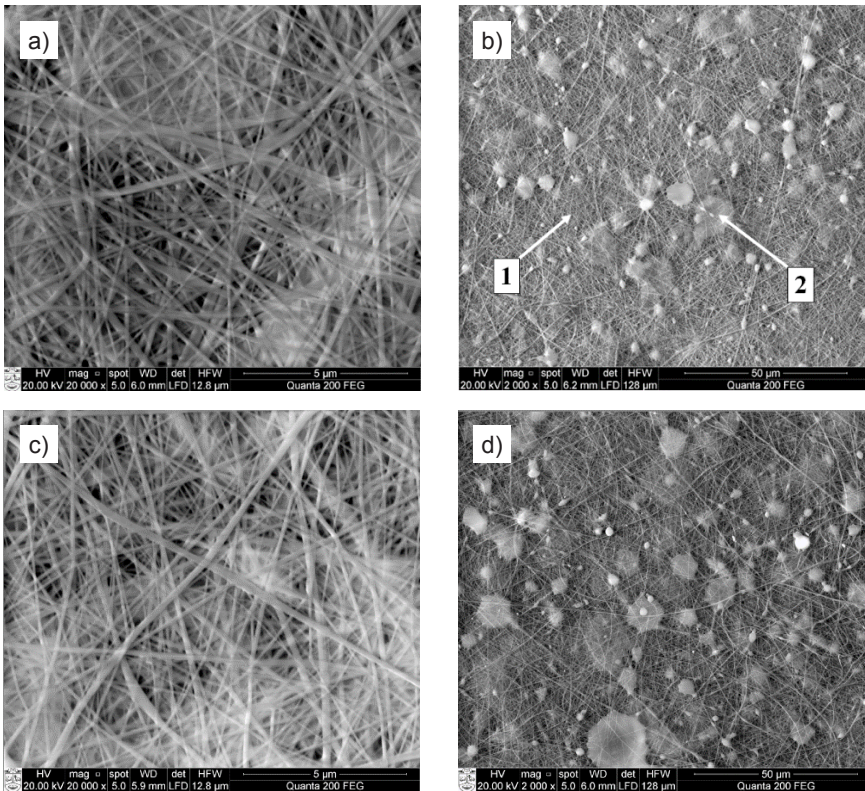


Figure 2. SEM images of electrospun nonwoven material from: a, b) pure PVA (viscosity $\eta = 504 \pm 60$ mPa-s; average of nano-microfibres diameter ($n = 200$, $\alpha = 0.9$) $d = 125 \pm 16$ nm) (number 1 indicates electrospun fibres, number 2 spots of polymer solution); c, d) bicomponent PVA/PAE 3 (70%/30%) solution ($\eta = 416 \pm 35$ mPa-s; $d = 130 \pm 17$ nm); a, c) scale $5 \mu\text{m}$, b, d) scale $50 \mu\text{m}$.

nonwovens mats, as was confirmed by SEM (comparing **Figure 2.a - 2.d**). Electrospun nonwoven mats consist of thin pure PVA (**Figure 2.a**) as well as bi-component PVA/ PAE (**Figure 2.c**) nano-microfibres and spots of polymer solution on their surface (**Figure 2.b - 2.d**).

Evaluation of the influence of the concentration of phenolic acids in PAE on the structure of the electrospun nonwoven mat confirmed the absence of visual differences in the structure of electrospun bicomponent PVA/ PAE nano-microfibres, as can be concluded from the SEM images presented in **Figure 3.a - 3.f**. The amount of PAE in the electrospun solution also had no effect on the structure of the electrospun nonwoven mats (**Figure 4.a - 4.f**).

The diameter distribution of electrospun nanofibres with different concentrations of phenolic acids PAE (PAE 1-2.2mg/ml, PAE 2-1.3mg/ml, and PAE 3 - 0.8 mg/ml) are presented in **Figure 5.a - 5.c**. Most (50-60%) of the electrospun nano-microfibres were of a diameter in the range from 100 to 200 nm (**Figure 5.a**). The same tendency of nanofibre diameter distribution was determined when the

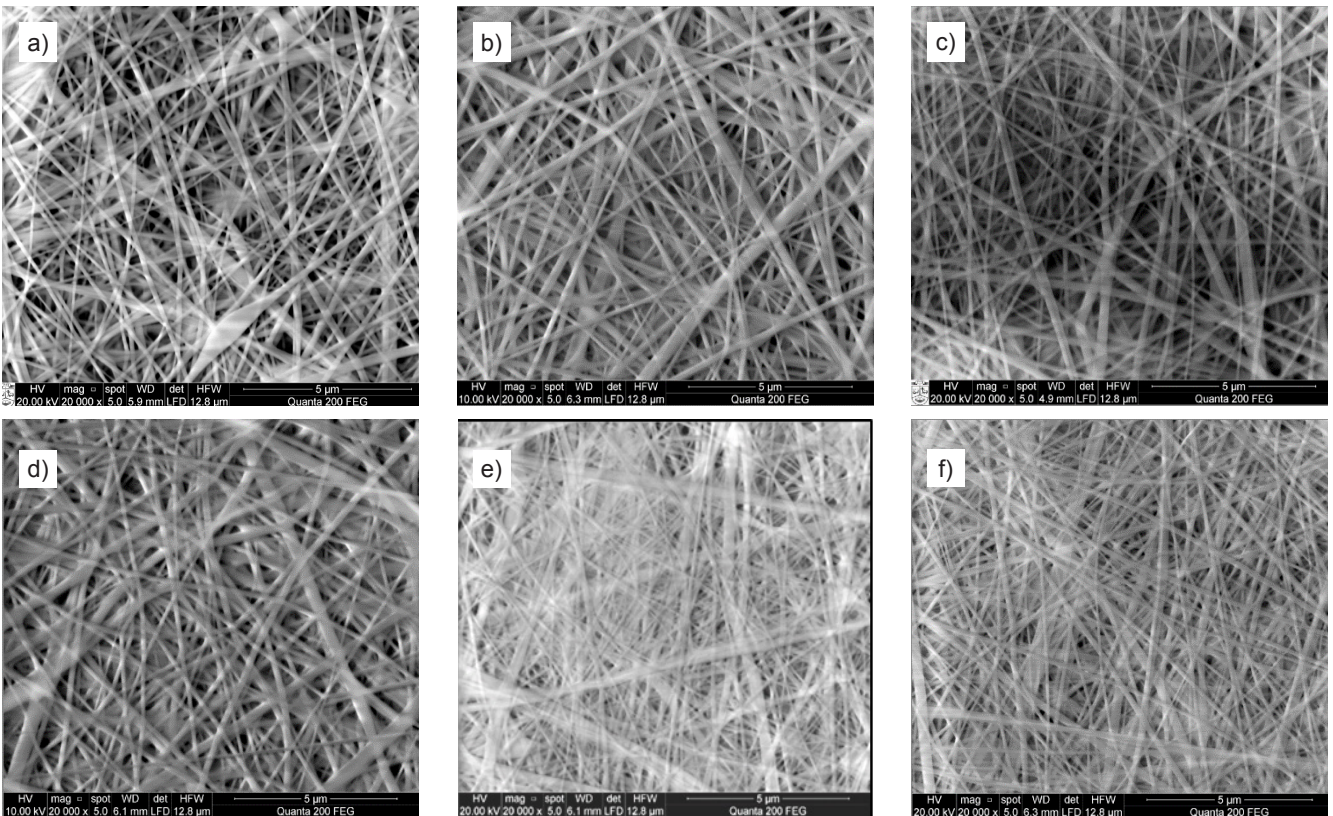


Figure 3. Influence of the concentration of phenolic acids in aqueous propolis (PAE) on structure of electrospun nonwoven mat. SEM images (scale $5 \mu\text{m}$, magnification $20\,000\times$) of electrospun nonwoven material from: a) PVA/PAE1 (90%/10%) average nanofibre diameter ($n = 200$) $\bar{d} = 140 \pm 16$ nm; b) PVA/PAE2 (90%/10%) $\bar{d} = 140 \pm 12$ nm; c) PVA/PAE3 (90%/10%) $\bar{d} = 135 \pm 15$ nm; d) PVA/PAE1 (50%/50%) $\bar{d} = 155 \pm 17$ nm; e) PVA/PAE2 (50%/50%) $\bar{d} = 130 \pm 15$ nm; f) PVA/PAE3 (50%/50%) $\bar{d} = 130 \pm 12$ nm.

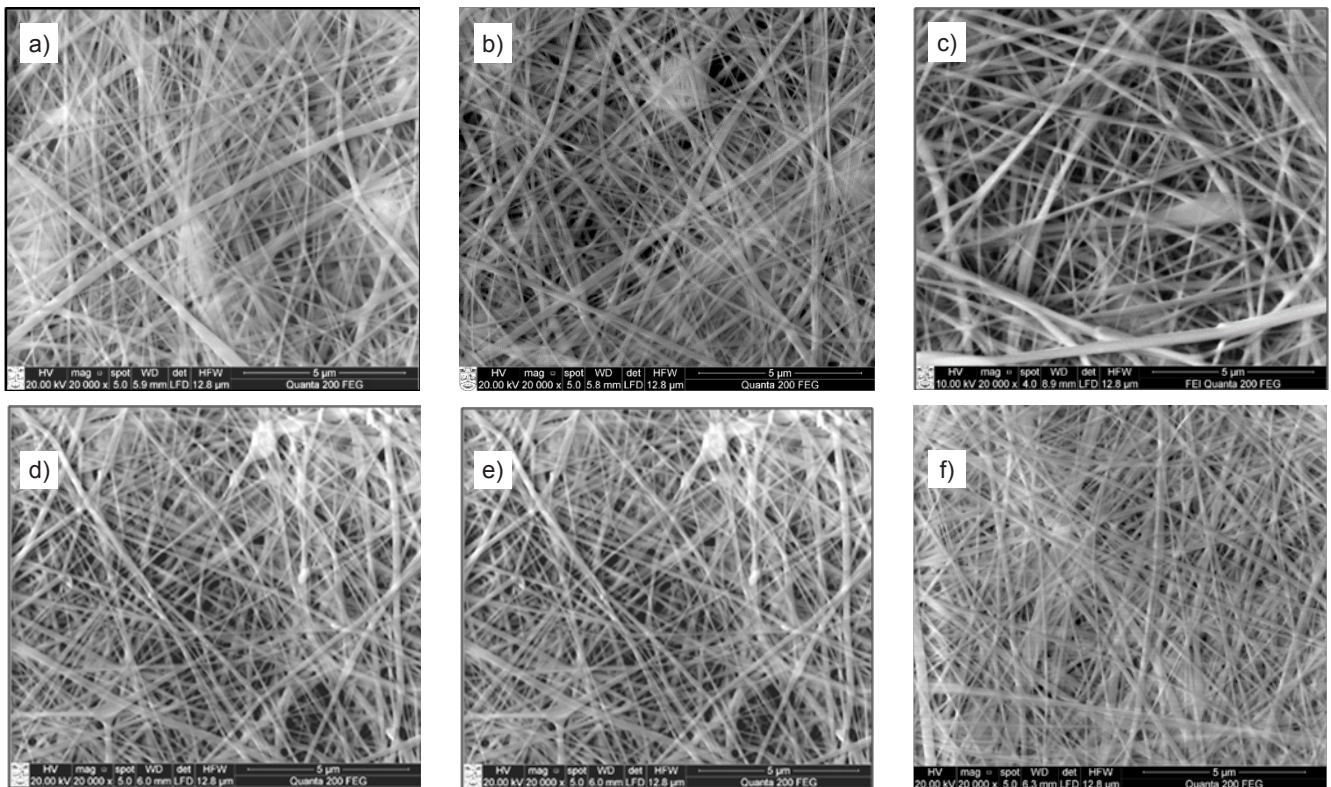


Figure 4. Influence of the amount of aqueous propolis on the structure of electrospun nonwoven material. SEM images (scale 5 μm, magnification 20 000×) of electrospun nonwoven material from: a) PVA/PAE1 (90%/10%) average nano-microfibre diameter ($n = 200$, $\alpha = 0.9$) $\bar{d} = 140 \pm 16$ nm; b) PVA/PAE1 (70%/30%) $\bar{d} = 135 \pm 16$ nm; c) PVA/PAE1 (50%/50%) $\bar{d} = 155 \pm 17$ nm; d) PVA/PAE3 (90%/10%) $\bar{d} = 135 \pm 15$ nm; e) PVA/PAE3 (70%/30%) $\bar{d} = 130 \pm 17$ nm; f) PVA/PAE3 (50%/50%) $\bar{d} = 130 \pm 12$ nm.

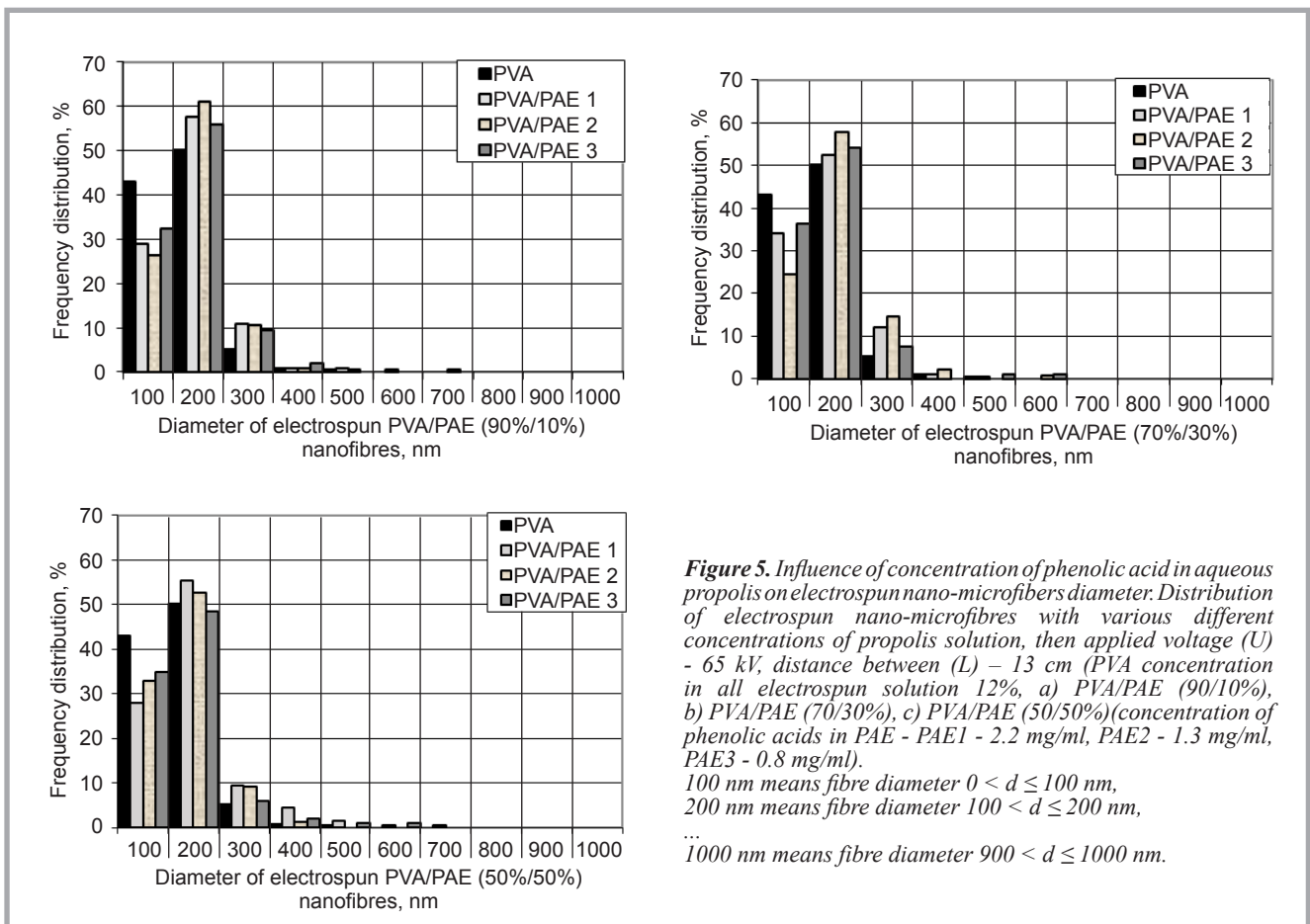


Figure 5. Influence of concentration of phenolic acid in aqueous propolis on electrospun nano-microfibres diameter. Distribution of electrospun nano-microfibres with various different concentrations of propolis solution, then applied voltage (U) - 65 kV, distance between (L) - 13 cm (PVA concentration in all electrospun solution 12%, a) PVA/PAE (90%/10%), b) PVA/PAE (70%/30%), c) PVA/PAE (50%/50%) (concentration of phenolic acids in PAE - PAE1 - 2.2 mg/ml, PAE2 - 1.3 mg/ml, PAE3 - 0.8 mg/ml).
 100 nm means fibre diameter $0 < d \leq 100$ nm,
 200 nm means fibre diameter $100 < d \leq 200$ nm,
 ...
 1000 nm means fibre diameter $900 < d \leq 1000$ nm.

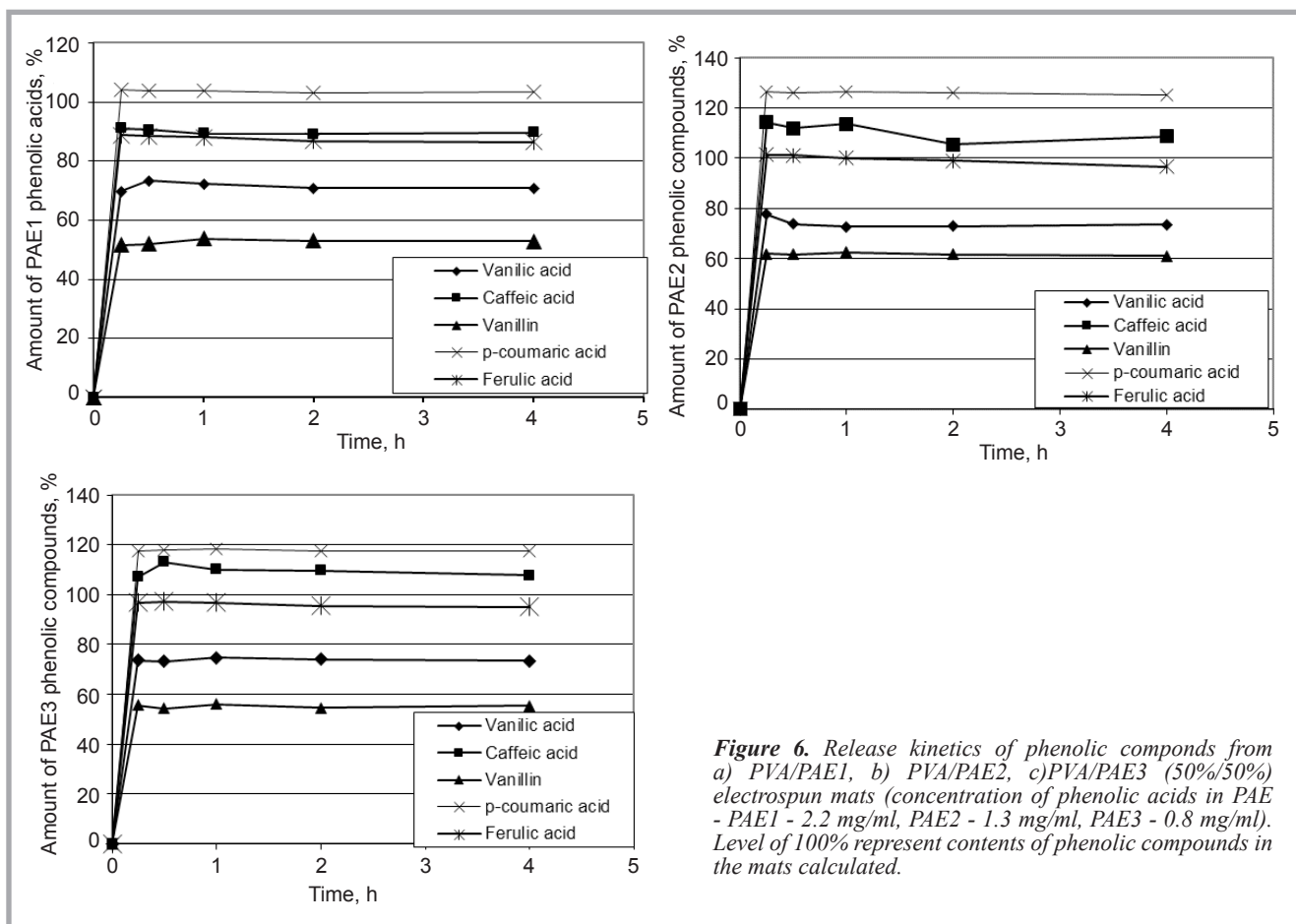


Figure 6. Release kinetics of phenolic compounds from a) PVA/PAE1, b) PVA/PAE2, c) PVA/PAE3 (50%/50%) electrospun mats (concentration of phenolic acids in PAE - PAE1 - 2.2 mg/ml, PAE2 - 1.3 mg/ml, PAE3 - 0.8 mg/ml). Level of 100% represent contents of phenolic compounds in the mats calculated.

amount of PAE in the PVA solution was 30% (**Figure 5.b**) and 50% (**Figure 5.c**).

Analysing the distribution of electrospun nanofibres with a diameter up to 100 nm, it is possible to notice the tendency that the thinnest nanofibres dominated (44%) when the PVA solution contained no additives. 20 - 33% of nanofibres with a diameter up to 100 nm was measured for electrospun bicomponent PVA/ aqueous propolis mats (PVA/PAE1, PVA/PAE2, PVA/PAE3).

The ability of the nano-microfibres produced to release phenolic acids was tested by applying a modified version of the dissolution test (methods of testing are described in the section *In vitro release study of phenolic acids from electrospun nonwoven mats*).

Nano-microfibre mats containing PAE dissolved in less than 15 minutes after contact with the water medium, resulting in a transparent mat fragment remaining from the nano-microfibre mats tested. After 15 min, up to 86% of phenolic compounds were released when a nano-microfibre mat was produced using PVA/PAE1.

Mats produced using PVA/PAE2 and PVA/PAE3 released 96% and 91% of phenolic compounds, respectively (**Figure 6**). Changes in the dissolved quantities of phenolic compounds were negligible at later sampling time points.

Propolis collected in Lithuania can be identified by dominating ferulic and coumaric phenolic acids that could be considered as specific quality indicators for propolis raw material and a preparation containing propolis [19]. Dissolution profiles for individual phenolic compounds were determined as similar and comparable to the dissolution of the total phenolic compounds evaluated. At 15 min, sampling points 52 - 62% and 70 - 77% of vanillin and vanilic acid had dissolved, respectively. In this study the biggest amount of p-coumaric phenolic acid, caffeic acid and ferulic acid were dissolved from PVA/PAE1, PVA/PAE2 and PVA/PAE3 (50%/50%) electrospun mats. The dissolution of caffeic, coumaric, and ferulic acids after 15 min of dissolution approached 100%. The quantities of phenolic acids released were evaluated by comparing them to theoretically calculated quantities of phenolic ac-

ids in the mats produced and considering the composition of the respective PVA polymer/PAE solution. Released quantities of some phenolic acids exceeded the theoretical 100% level, showing a full release of the phenolic acids analysed.

Thus it is reasonable to conclude that mats electrospun from biocomponent PVA/ aqueous propolis nano-microfibres could be considered for developing drug delivery systems for the local supply of propolis compounds.

Conclusions

The production possibility of electrospun nonwoven mats from PVA with propolis aqueous extract was confirmed. No significant effect of phenolic acids in the PAE concentration on the structure of electrospun nonwoven mats was determined. In all cases nonwoven mats were formed containing smooth nano-microfibres and polymer spots on the surface.

The fraction of thinner nanofibres (diameter <100 nm) increased when mats were electrospun from PVA solution containing no added substances. From bicom-

ponent PVA/aqueous propolis solutions fewer (in average about 20%) nanofibres with a diameter up to 100 nm were electrospun.

The antioxidant activity of propolis is defined by the profile of phenolic compounds available. Vanilic acid, caffeic acid, vanillin acid, p-coumaric acid, and ferulic acid were released from electrospun PVA/PAE1, PVA/PAE2 and PVA/PAE3 (50%/50%) mats.

It is possible to conclude that mats electrospun from bi-ocomposite PVA/aqueous propolis nano-microfibres may have potential application as fast and controlled drug delivery systems. Thus it should be considered necessary to evaluate the stability of the electrospun mats, including testing their ability to dissolve and release individual propolis compounds in a reproducible manner. In a further study, the release kinetics of phenolic acid from stabilised electrospun nano-micro fibres will be analysed. Application of the electrospinning technique for the development of controlled delivery systems of propolis phenolic acids should be evaluated as offering significant advantages in treating local infections.

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