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Polylactic acid and lanolin based nanofibrous structures for wound management application

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Polylactic acid (PLA) polymer and wool oil (lanolin) have been used to develop nanostructures for wound dressing management. Lanolin has been extracted from raw wool surfaces and used as a by-product in wide range of pharmaceutical areas. Different solutions with varying concentration of the PLA/lanolin and sodium alginate/lanolin solutions have been prepared and then nanostructures are developed using electrospinning method. The developed structures are aimed to use as smart wound dressings. During the production stage, the parameters of the electrospinning process have been changed to develop the optimum structures. The effect of solution concentrations on the applied voltage and the distance between the pipette tip and the collector is highlighted. The spinnability of lanolin is the main objectives of this study and the PLA/lanolin nanostructures are designed and manufactured successfully. The essential test methods have been performed to measure the usability of the produced materials as wound dressings. These are liquid absorption capacity, horizontal/vertical wicking, SEM, degradation, pH, antibacterial assay, and tensile properties. From the tested parameters, it is obviously found that the use of PLA/lanolin as wound dressing is suitable according to initial *in vitro* test results.

Keywords: Lanolin, Medical textiles, Nanostructures, Polylactic acid, Wound dressings, Wood oil

1 Introduction

In today's world, sustainability, recycling, upcycling, and renewability are crucial and challenging. Nowadays, the priority is on the disposal of wastes produced by mass production industries, such as textile industry. The utilization of textile raw materials is so prevalent; however, the limited parts of these materials are used in textile manufacturing. Textile raw materials-based wastes are not used as by-product for smart or technical textiles. Within the globalizing world with the impact of industrialization and urbanization, the existing assets are utilized unknowingly. Wastes are generated as a result of this consumption of limited resources. The textile industry generates more than 13 million tons of industrial waste per year only in Turkey. Only 57% of this amount is recyclable[1], and this percentage increases with the selection of proper raw materials as well as by using modern recycling systems. There are large amounts of waste generation, during the production activities and after the consumption[2]. Recycling, which has a great influence on sustainable development, enables the re-processing, production and re-use of previously collected materials. It needs to be clearly realized that there cycling and upcycling are not optional, they are mandatory.

Another critical issue in the production process is generation of by-products. While the main products are produced in industrial or biological production line, the by-products that are of secondary importance are also generation at the end of the production process[3]. By-products are generally small in quantity and have less value as compared to the core/main product. To give an example from the textile industry, the resulting cottonseed during the production of cotton fibre has become an important by-product for different applications[4]. This by-product is suitable for cottonseed oil production for both food and industrial applications, and subsequently after the oil extraction, the residue is used as animal pulp. Despite this well-known example, most of the raw material production wastes cannot be considered as by-products. Waste is classified by source and composition, and the waste disposal processes are applied partly or wholly on wastes. Such waste disposal process is generally needed in the animal production fibre process. Especially in wool processing, where wet processing is one of the most common steps, a lot of pollutants are discharged as wool washing is one of the main steps to get the pure wool. The wool oil/wax/grease (lanolin) comes up after the washing and cleaning

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process which can be determined as harmful element for the environment due to its nature. Different refining methods for "purification" of lanolin are developed to use it as medical products[5]. Previously, the wool wax extraction process was merely a version of the modern foam buoyancy process. Wool washing waters were poured from a height into a hopper, so that wool wax was foamed and deposited on the surface of the water. It was then stripped and allowed to collapse by separating the wool wax onto the surface. Technical advances included a method of acid precipitation, which made wool wax unstable, separating the wax into a lower sludge that could be filtered, and the addition of metals would cause wax coagulation in the trivalent state. Finally, the extraction procedure was performed with a centrifugal separator, which brought the new millennium as the preferred modern extraction method[6].

The structure of wool is shown n Fig. 1. The substance, called wool wax, is soluble in organic solvents, yellowish white in color and similar to the wax[8]. Additional wastes are also produced after this process. Wool wax, which is similar to cotton wax and other waxes known for difficult saponification, is troublesome to saponify even with alcoholic potassium hydroxide. The method of removing wool wax from untreated wool, which can be recovered from the washing bath if desired, is carried out by emulsifying the washing bath during the wool washing process. The recovered oil from the washing bath has a high marketing value. When it first leaves the washing bath it is dirty yellow. After the sheep's scent is cleaned with some processes, it is turned into an odorless, light-yellow color with a high marketing value and having a melting point of 38-44 °C. Because of its good properties in the cosmetic industry, the cleaned wool wax is blended with paraffin and water to obtain the substance lanolin[9].

Lanolin hasan excellent anti-fungal and anti-bacterial properties. It is used to soften and treat the dry skin of lips or nipples. It is considered as an emollient because it can help soothe and smooth dry, cracked, or dehydrated skin[10-12]. It's also an occlusive moisturizer and it can slow water loss from skin. It can be found in many types of beauty products, such as lotions, makeup, eye drops, sunscreen[13] and shaving creams or gels. Lanolin, which is 98% ester, consists of a mixture of fatty acid and fatty alcohol in half. It is scientifically proven that pure lanolin is beneficial for new mothers to protect their sensitive skin. It can be used to relieve painful, dry and cracked nipples caused by breastfeeding[11,14]. The most common and irritating indications of chemotherapy are dry and cracked lips. During the chemotherapy process, fat is lost from the skin and this can lead to mouth pain and severely chapped lips. Lanolin-based products are often prescribed to patients because lanolin are close linked to the body's fats[11,15]. Lanolin imitates the chemical structure of human skin exceptionally close, showing that pharmaceutical companies utilize it as a carrier to deliver certain drugs subcutaneously. It has also been used in ophthalmic drugs. Lanolin is also one of the most frequently used substances in eye drops because its antibacterial and moisturizing properties are effective in soothing dry eyes and protecting them from infection[10,11]. It is widely used in baby preparations for the treatment of wound caused by breastfeeding mothers, burn aids to keep the wound dry and soft, in make-up materials, hair protection and spray

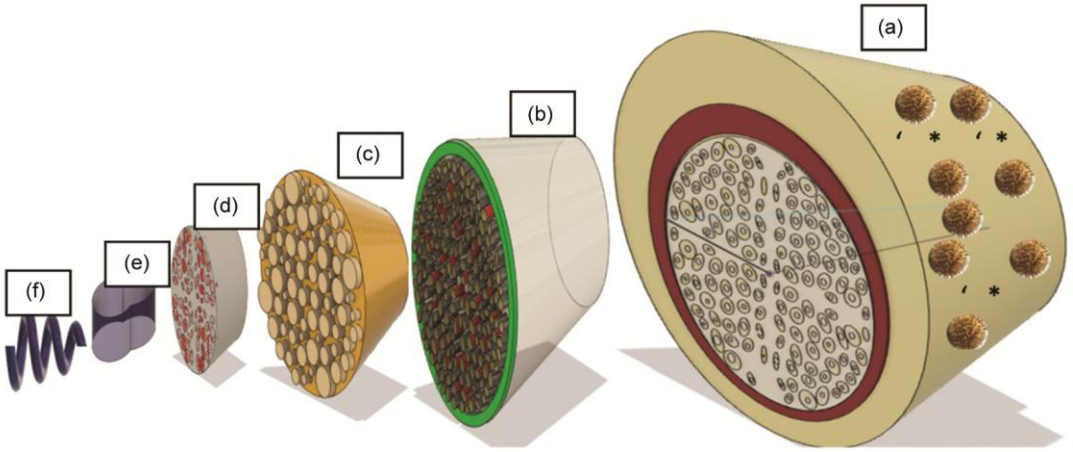

Fig. 1 — Structure of wool (a) cuticula, (b) cortex cell, (c) macrofibril, (d) microfibril, (e) molecular chain, and (f) alpha helix[7]

plasticizers, to soften irritated skin in shaving creams, pet products and many other areas[13,16]. Commercially, the utilization of lanoline in medical cream can be found for burn wound treatment. It is well-established that lanoline has reepithelization rate, thickness of the dermis and cell counting impact[14,17].

Polylactic acid (PLA) obtained by biological methods from renewable sources, such as corn starch or sugar cane, are environmentally friendly. PLA is biodegradable and requires 20-50% less fossil fuel in production than other petroleum-based synthetic fibre. The use of PLA at the electrospinning process is well-established and there are a number of studies which highlights its technical and structural benefits as a base material[18-21].

The primary object of this study is to develop novel lanolin added nanostructures that may be applied to the second degrees wounds, which entail smart wound dressings is to protect the burn wounds. The scaffold acts as a barrier among air and skin. It prevents the connection between bacteria, germ, dust and wound. Moreover, it is aimed that the wound dressings provide suitable environment to facilitate and accelerate the healing process. There search, published recently[7] on the use of lanolin as reinforcement materials to develop 3D-printed structures, provides promising results to employ lanolin to develop medical textiles.

In this study, nanofibrous structures have been designed and fabricated through the electrospinning technique. The developed structures are aimed to use as a smart wound dressing, which will minimize the pain during the process of healing and accelerate wound healing and tissue repair. The general and overarching goal of this work is converting a *by-product* to smart medical textiles to provide a new perspective on textile-based bio-wastes.

2 Materials and Methods

The material selection was done after conducting different trials with sodium alginate (SA) and polylactic acid. It is important to mention that despite of conducting many trials of SA/lanolin combination, it could not be converted into nanostructures after the lanolin addition. Then, PLA was selected to employ as a base material for further study, as it possesses beneficial properties for wound dressing materials such as high absorbency and biodegradability. In the electrospinning process, dichloromethane (DCM) and dimethyl formamide (DMF) were used as a solvent (Sigma-Aldrich, Istanbul, Turkey). The wool wax was kindly provided by Pozitif Wool Ltd., Uşak, Turkey. The raw wool wax contains various dirt and foreign materials, such as clumps of hay, burrs or manure. The Soxhlet extraction device was employed to remove foreign materials and dirt. The Soxhlet device in the Public Health Laboratory of Istanbul Provincial Health Directorate No. 1 was used for determining the amount of the foreign materials in raw wool wax. The nanostructures were prepared using electrospinning system (Invenso, NE300 NanoSpinner, Istanbul, Turkey) (Fig. 2).

3 Results and Discussion

Soxhlet device was used to determine the amount of dirt and foreign materials soluble in hexane. The raw wool oil was taken onto standard filter paper and it was weighed. The sample taken into the filter paper was folded so that it did not protrude out into the Whatman 603G Thimble. The thimble was then placed in the extractor chamber of the Soxhlet extraction device. Refrigerant was placed in the extractor and extraction was performed with hexane. The balloon tare used in the extraction was 112.3776 g. The amount of sample taken was 5.35 g. After the extraction process, the solvent in the flask was evaporated at 60°C and the amount of oil was determined. After the process, 88% of the sample taken shows the amount of oil and 12% shows the amount of foreign matter. Pre and post process of wool vax are shown in Fig. 3. Wool oil amount was calculated using the following equation:

$$\text{Wool oil amount} = [(117.0611 - 112.3776)/5.35] \times 100 = 87.54\%$$

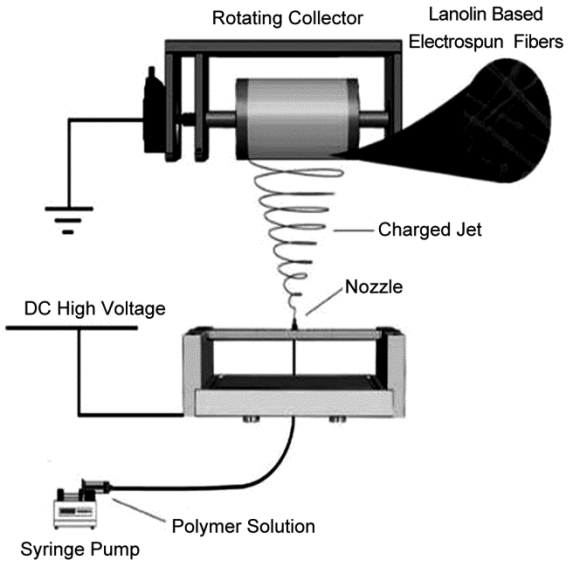

Fig. 2 — Inovenso NE300 electrospinning system

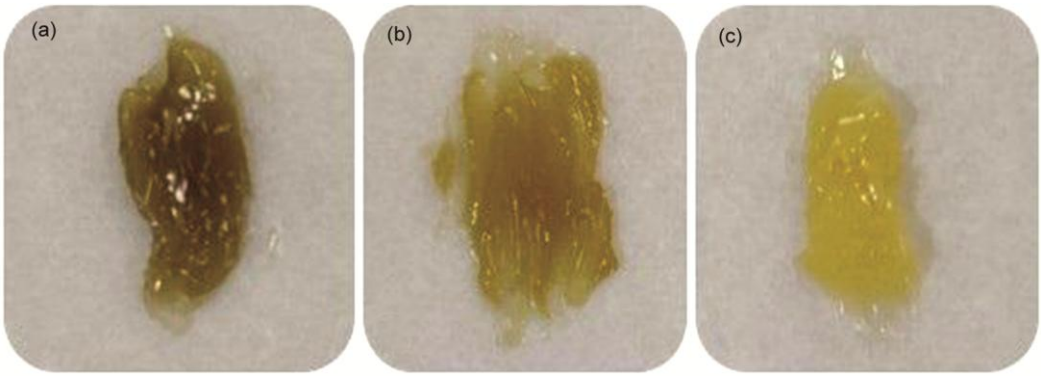

Fig. 3 — Extraction process of wool wax (a) dirty lanolin, (b) pre-extraction, and (c) main extraction (purified)

3.1 Nanofibre Spinning Trials with Wool Oil (WO)

3.1.1 Sodium Alginate/Wool Oil (99.5 /0.5wt %) Electrospinning

At the first electrospinning trial, 99.5 wt. % of sodium alginate solution was mixed with 0.5 wt. % of wool oil solution. Tetrahydrofuran was used as the solvent for the wool oil solution. The spinning parameters determined were: voltage 18 kV, between collector and nozzle 25 cm distance, flow rate 1 mL/h, and collector 100 rpm/h moving right-left. A number of different parameters were applied to produce nanofibre. However, the fibre form/structure was not observed in any combination of SA. It could be presumed that perhaps both sodium alginate (which forms viscous colloidal solution with liquid media/sparingly soluble in some solvents) and lanolin (which is technically oil/wax) affect various process parameters of electrospinning, such as viscosity, needle clogging, volume feed rate and formation of Taylor cone.

Although different trials were carried out; however, due to the chemical interaction between alginate and wool oil, the fibrous nanostructures could not be obtained but further detailed research is needed on chemical interaction of alginate and wool oil to determine the root cause of this problem. It is surprising that in the previous study, SA/lanolin was processed by making use of 3D (additive manufacturing) method[7].

3.1.2 PLA/Wool Oil (99.5 /0.5wt %) Electrospinning

In the second electrospinning trial, the polylactic acid (PLA) concentration was determined as 8% and the wool oil concentration was determined as 10 wt %. For 10 wt % wool oil solution, 1g wool oil was added to 10 mL tetrahydrofuran by weighing on a balance scale and homogenous solution was obtained by stirring for 15 min with magnetic stirrer at the room temperature (20 ^{0}C). The solution was prepared by mixing 4:1 (v/v)dichloromethane/ dimethylformamide solvents for 8 wt. % PLA solution. 20 mL of dichloromethane and 5 mL of dimethylformamide were extracted for the solution. The solution was weighed with 2 g of PLA on a balance scale and stirred for one hour at 100 rpm/min on a magnetic stirrer. For 0.5 wt. % wool oil solution, 10 mL of total solution was taken from 0.05 mL wool oil solution with micropipette. PLA solution (99.9 wt. %) was taken from 9.95 mL PLA solution. This amount of solution taken in a beaker was stirred for 15 min using a magnetic stirrer for obtaining a homogeneous mixture. The viscosity and conductivity of the prepared solution were measured before drafting. (viscosity 80 cP, 16%) and (conductivity 1 µS/cm at 21.7 °C). The distance between the nozzle and the collector was 28 cm, the attraction voltage was 30 kV, the flow rate was 0.5mL / h, and the collector rotation speed was determined as 100rpm. The ambient temperature was 21°C. The structure formation was conducted under these conditions.

3.1.3 Optimization of 100 wt. % PLA Nanofibre

After different trials, the optimum parameters of PLA electrospinning were determined by changing the distance, voltage and flow rate. The selected polymer solution was prepared with a PLA concentration of 8 wt. %. The solution was prepared with addition of 3% (w/v) Tween 80 as surfactant material. The solution was prepared by stirring 1.2 g PLA in 0.5 mL Tween 80 with magnetic stirrer at room temperature (20 °C±2 °C) for 2 h in 15 mL of solvent. The solution viscosity was 87 cP 17.5%, conductivity 4 µS/cm 22.4^{o}C. The parameters of the electrospinning experiments are given in Table 1. The ambient temperature was kept constant as 21^{o}C and the rotational speed of the collector was set as 100 rpm/h. The samples were compared and the final production was carried out with the parameters of

Table 1 — Optimum parameters for nanofibre electrospinning

Trial No.	Voltage, kV	Distance, cm	Flow rate, mL/h
1	35	16	1.8
2	35	15	1.8
3	35	14	1.9
4	34	13	1.9
5	34	12	1.9
6	34	12	2.0
7	34	12	2.5
8	34	11	1.9

Trial 5. In general, the high PLA ratio affects the production parameters positively.

3.2 Wound Dressing Production

3.2.1 PLA / Wool Oil Ratio (99.5/0.5 wt. %)

The final production was done in accordance with the optimum electrospinning parameters for each and every solution combination. The 100% PLA production parameters were taken as reference; however, it was adopted according the lanolin ratios. The production was carried out by partially changing the electrospinning parameters with the presence of lanolin and the parameters are: 15 mL solution was prepared with 8% PLA and 1.2 g of polymer was weighed into the solution on a balance scale. The solvent ratio used was: 12 mL dichloromethane and 3 mL dimethylformamide (4:1 v/v). The solution was stirred using a magnetic stirrer for 2 h at 300 rpm. After homogeneous dissolution, 3% Tween 80 (0.5 g) was added to the solution and stirred for a further 10 min in the magnetic stirrer. On the other hand, the wool oil solution was prepared in a separate beaker at a concentration of 10%, containing 0.4 g of oil in 4 mL of dichloromethane solvent. Viscosity and conductivity measurements were carried out by taking 14.925 mL of polymer solution and 0.075 mL (75 µL) of oil solution in 15% magnetic stirrer. Viscosity 75 cP (15%) and conductivity 3.24 µS at 20°C were measured.

Production parameters were voltage 34 kV, ambient temperature 21°C, flow rate 1.6 mL / h, distance between nozzle and collector 12 cm and collector rotation speed 100 rpm. Production was carried out for 2 h in these parameters. Assuming that the whole solution is used in the whole production, it can be said that the produced material contains 0.0075 g wool oil and 1.194 g polylactic acid, considering losses.

3.2.2 PLA / Wool Oil Ratio (99/1 wt. %)

The polymer and wool oil solution was prepared at the same concentration as given in the previous section **3.1.2**. The viscosity of the prepared solution was measured as 73.5 cP 14.7% and the conductivity was 4.2 µS at 21.50°C. Production parameters were: voltage 32 kV, ambient temperature 170°C, although it was observed to increase to 20°C in time, flow rate 1.9 mL / h, distance between nozzle and collector 12 cm, and collector rotation speed 100 rpm. Findings show that it contains 0.015 g wool oil and 1.188 g PLA.

3.2.3 PLA / Wool Oil Ratio (97/3 wt. %)

Tween 80 was added to the solution in 3 wt. % concentration (PLA), as per the method given in previous section **3.2.1**. 4 wt. % concentration (PLA) was added. The viscosity of the prepared solution was measured as 74.5cP (14.9%) and the conductivity as 4.6 µS at 23.8°C. The production parameters were voltage 32 kV, ambient temperature 21°C, flow rate 1.9 mL/h, distance between nozzle and collector 12 cm, and collector rotation speed 100 rpm. The content of the production includes 0.045 g wool oil and 1.164 g PLA.

3.3 Lateral and Vertical Liquid Absorption Test

It is anticipated that wound dressings make sure that pooling of exudate cannot take place at one point. In other words, enhanced lateral and vertical wicking minimizes, the pooling of exudate at one point[19]. The basic characteristics of wound management are maintaining a moist environment at the wound surface and the removal of excess fluid from wound skin to prevent maceration or disintegration of the wounds. For lateral and vertical liquid absorbency testing, 0.23 g of sodium chloride and0.04 g of calcium chloride dihydrate (Merck) in 100 mL of distilled water were weighed on a scale and mixed until homogeneous. Remazol Red RR (DyStar) was added to the mixture with a spatula. For the lateral wicking test, 3×3 cm test specimens were cut. One drop of the prepared test solution was dropped by a pipette to the center of the cut test specimens. The images of lateral wicking absorption test are given in Fig 4.

Due to the nature of the wool oil, the developed structures lateral area wicking of fluid across the wound dressing is limited. After the lateral and vertical absorption test, it is clearly seen that the use of wool oil in PLA nanostructure does not affect the absorption properties of PLA (Fig 4.). The WO addition does affect the tested parameters as expected; however, it still has enough wicking behavior. The minimum lateral wicking was seen at the highest WO reinforced structures.

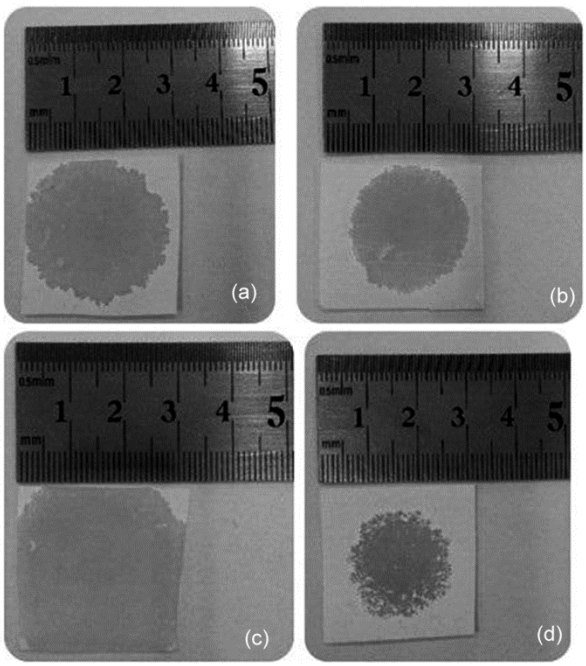

Fig. 4 — Lateral wicking test results (a) 100% PLA nanostructure, (b) 99.5/0.5% wt. PLA/WO nanostructure, (c) 99/1% wt. PLA/WO nanostructure, and(d) 97/3% wt. PLA/WO nanostructure

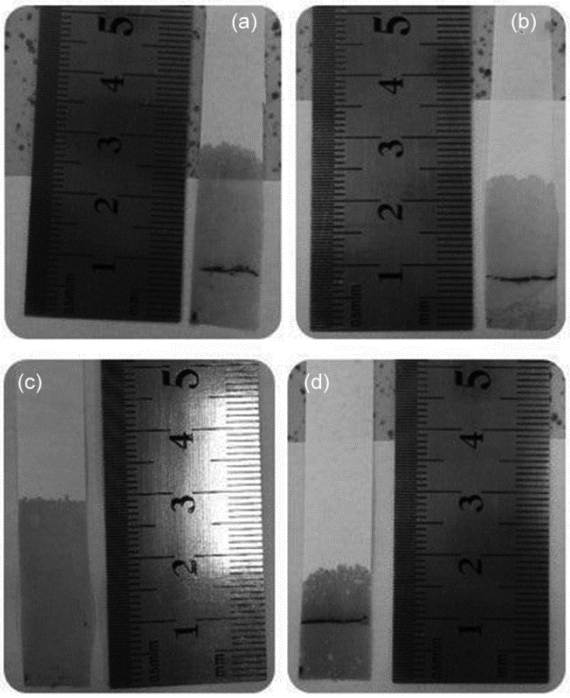

Fig. 5 — Vertical wicking test results (a) 100% PLA nanostructure, (b) 99.5/0.5% wt. PLA/WO nanostructure, (c) 99/1% wt. PLA/WO nanostructure, and (d) 97/3% wt. PLA/WO nanostructure

3.4 Vertical Liquid Absorption Test

For the vertical wicking test, 1×5 cm test specimens were cut. The prepared test specimens are marked with a reference point from 1 cm to be immersed in the test liquid. Each test sample was immersed in the test liquid for up to 60 s in the vertical position[19]. Images of vertical liquid absorption test are given in Fig 5. The minimum vertical movement was found to be around 8 mm for 3% WO reinforced structures. However, the vertical movement for 0.5 and 1.0 wt /% WO solutions are 20, 19 and 14 mm respectively.

The wet and dry weight values of the tested samples are shown in Table 2. As seen in the table, the absorption capacity decreases as the wool oil ratio increases in the structure. The changes are not noteworthy for wound dressing application. The structure absorbs enough wound liquid. It is important to mention that the wound needs to remain enough moist so that it does not get dry during the wound healing process. The healing process can be delayed just because of the dry wound[19]. The relation between the amount of wool oil and the liquid absorption capacity is inversely proportional. As the amount of wool oil used in the production increase, the liquid absorption capacity of the dressing is decreased. This allows the wound to remain moist. The liquid absorption capacity is calculated using the following equation:

Table 2 — Liquid absorption capacity measurements

Sample (wt. % WO)	Dry weight g	Wet weight g	After dried g	Absorption %
0	0.0225	0.1346	0.0233	83
0.5	0.0234	0.1285	0.0244	82
1	0.0153	0.1104	0.0160	86
3	0.0439	0.1648	0.0449	73

Water absorption capacity = (Wet weight-Dry weight) / (Dry weight) × 100

3.5 SEM Analysis

100% PLA fibre diameters vary between 493 µm and 1416 nm on this surface which is obtained from 100% PLA polymer (Fig. 6). The average fibre diameter was calculated as 694 µm. Generally, when the structure is examined, droplet formation is not observed and it is a uniform structure. The overall structures appear to be smooth and properly shaped as the fibres.

Figure 7 shows fibre surface consisting of 99.5 wt. % polymer material and 0.5 wt. % wool oil. The wool oil added to the structure caused a slight change in the overall web appearance. The finest fibre thickness in

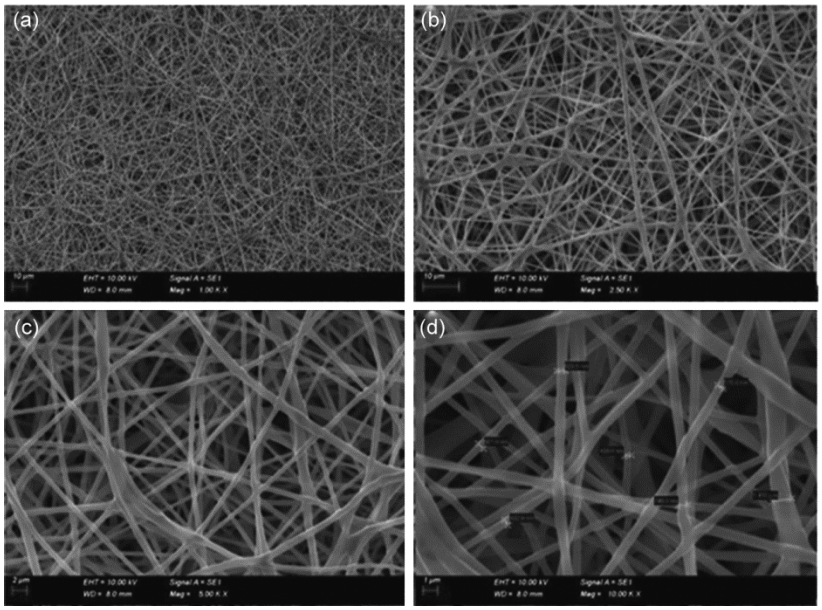

Fig. 6 — SEM images of 100 wt. % PLA (a) × 1.0k, (b) × 2.5k, (c) × 5.0k, and (d) × 10.0k magnification of structure

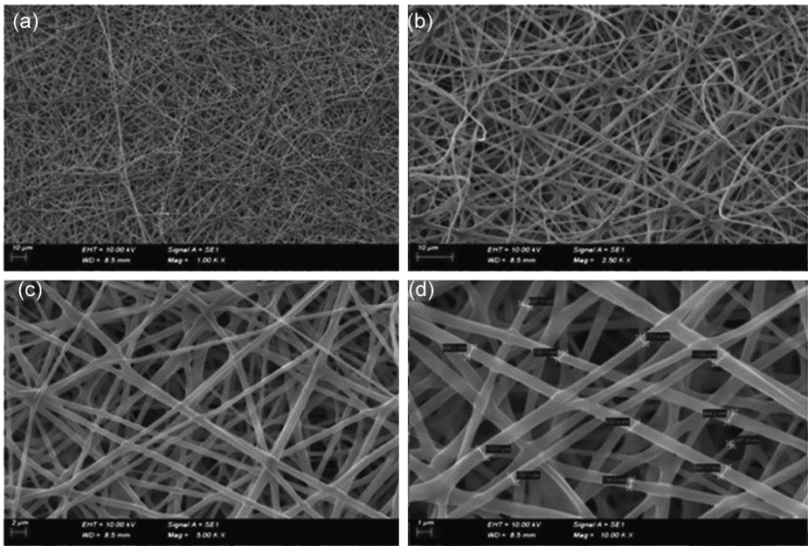

Fig. 7 — SEM images of 99.5/0.5 wt. % PLA/WO (a) × 1.0k, (b) × 2.5k, (c) × 5.0k, and(d) × 10.0k magnification of structure

the structure was 368 µm and the thickest fibre was 1238 nm. The average fibre diameter was calculated as 838 µm. No droplet formation was observed in the structure and it can be considered uniform.

There is 1 wt. % wool oil in this structure which contains 99 wt. % polymer material (Fig. 8). The overall web structure was evaluated as in the previous sample and is found uniform. Fibre diameters range from 464 µm to 906 µm. The average fibre diameter was relatively better than the previous sample and was calculated as 716 µm.

Figure 9 shows fibre structure containing97 wt. % polymer material and 3 wt. % wool oil. The average fibre diameters in this structure range from 442µm to 835µm. The average fibre diameter was calculated as 633µm. When the structure is examined, it is seen that there is bead formation at different places. It is found that the web structure has changed slightly compared to the previous samples. As known, these changes are caused by the change in electrospinning parameters.

In order to clearly observe the effect of the wool oil, the highest addition of WO ratio was tried in this sample where the general structure appearance is completely scattered. The polymer material and wool oil ratio is 85% and 15% respectively (Fig. 10). Average fibre diameter was measured as 2454 nm.

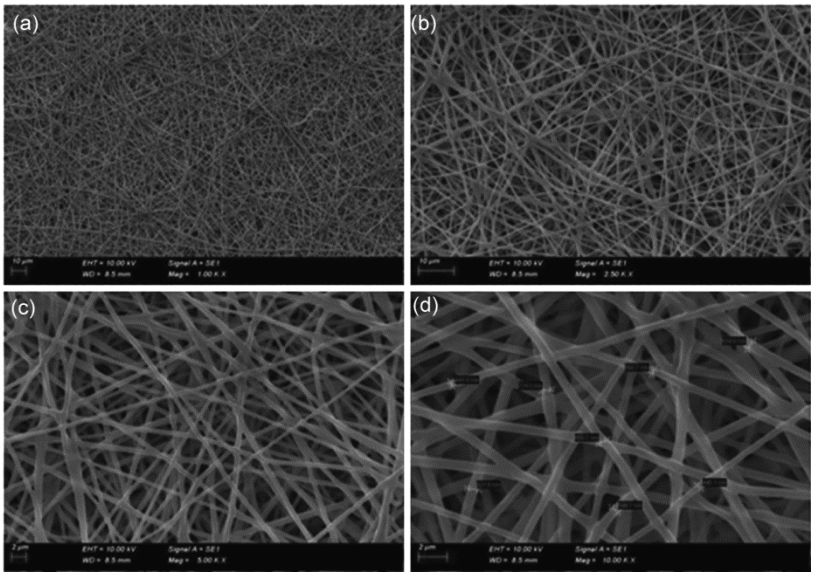

Fig. 8 — SEM images of 99/1 wt. % PLA/WO (a) × 1.0k, (b) × 2.5k, (c) × 5.0k, and (d) × 10.0k magnification of structure

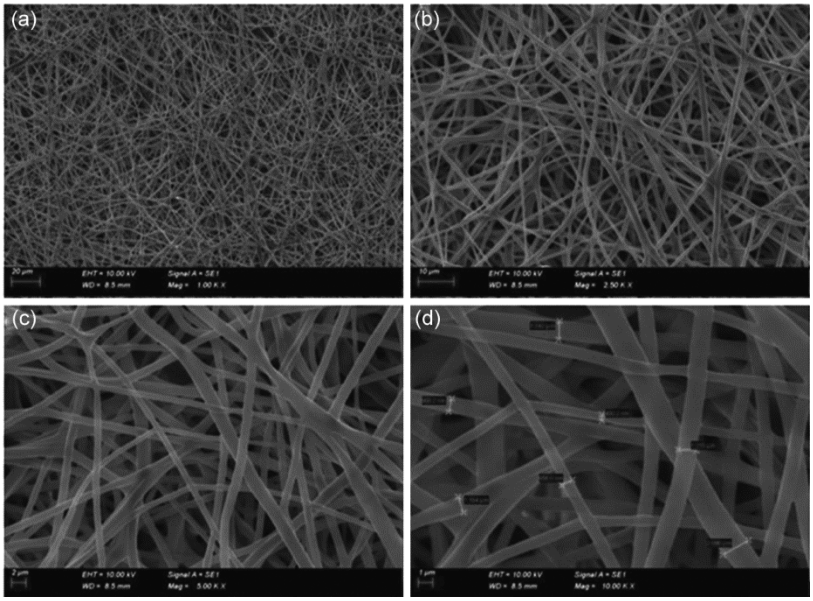

Fig. 9 — SEM images of 97/3% PLA/WO (a)×1.0k, (b) ×2.5k, (c) ×5.0k, and(d) × 10.0k magnification of structure

The fibre diameters were found to be in the range of 2104- 2802 nm which can be classified as thick fibre. Structural deterioration occurred with the increase in oil ratios. It should also be noted that such a high rate of wool oil may have different adverse effects on the wound, which might reduce the rate of wound healing or hinder the goal of wound healing.

3.6 Degradation Analysis of Structures

Degradation percentage is critical for the preservation of wounds. As mentioned before the wound dressing may act as physical barrier to prevent physical or chemical damage to the wound. Burn wounds are dynamic and alter in appearance, particularly within the first 48 h. The initial burn dressing should be one that will remain intact for 48 h and it will prevent the risk of infection. It is a protocol in the burn service to cover all burns with dressing for 48 h[22]. Therefore, degradation percentage is vital in 48h. During this study, the degradation tests were administered in appropriate time intervals; degradation was not visible and countable. At 72 h slight degradation was visible. The highest degradation percentage was in 97/3% PLA/WO ratio

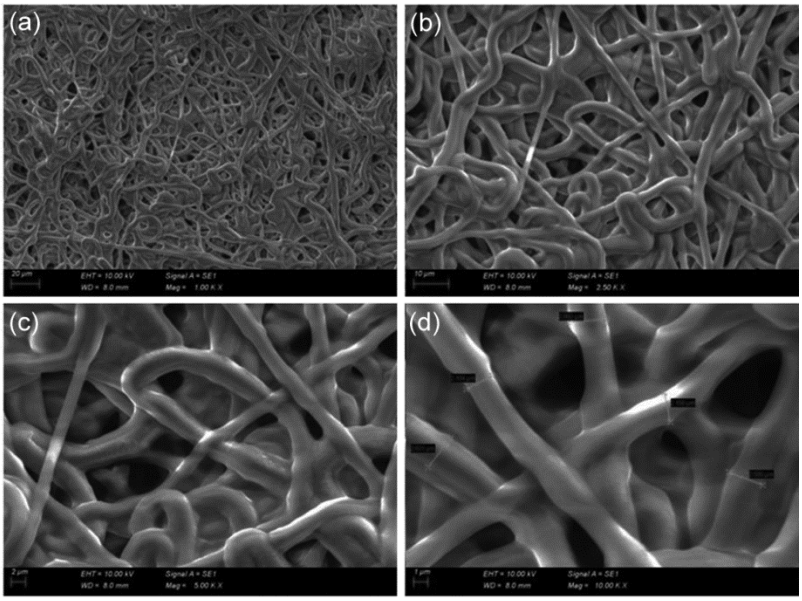

Fig. 10 — SEM images of 85/15% PLA/WO (a)×1.0k, (b) ×2.5k, (c) ×5.0k, and(d) ×10.0k magnification of structure

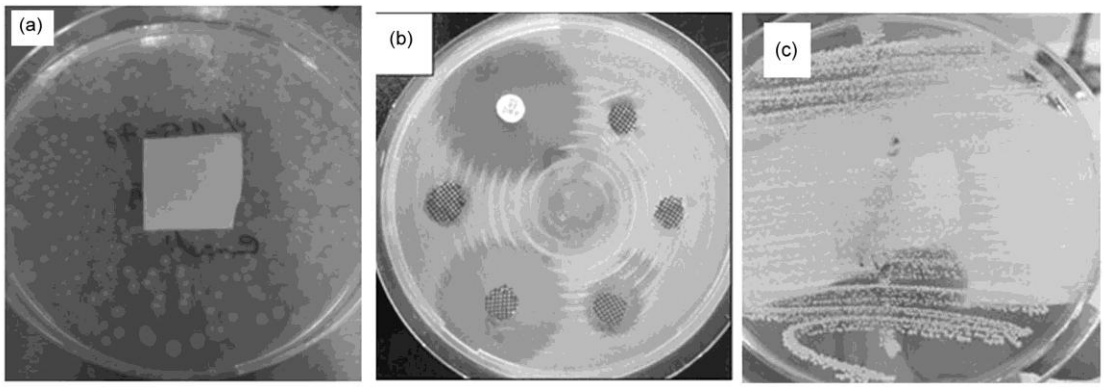

Fig. 11 — PLA/WO inhibition zone graph (a) WO solution, (b) 3D PLA/WO, and (c) 100% PLA

at the appropriate interval. The minimum degradation percentage was observed in lowest WO percentage at the appropriate interval. Therefore, the percentage of wool oil affects degradation behavior of the structure; consequently, as WO solution concentration increases, the degradation percentage increases which implies that they have a proportional relation. Similar results are observed at the 3D technique used lanolin structures[7].

3.7 Antibacterial Analysis of Structures

Two different bacteria were applied, namely *Staphylococcus aureus* (*S. aureus*) as Gram positive and *Escherichia coli* (*E. coli*) (ATCC:8739) as Gram negative. The antibacterial activity of all WO containing structures were tested but no notable antibacterial activity was observed [Fig. 11(a)]. However, antibacterial activity is clearly seen in Fig.11(b)[7] (Kirby-Bauer procedure). In the nanospinning method, either the production temperatures reduced the effect of the antibacterial activity of WO or the interaction of PLA and WO showed an inhibitory behavior the antibacterial activity. On the other hand, in the previous study,[7] the 3D surface obtained with the mixture of SA and WO showed very clear antibacterial properties. In future studies, the effect of parameters such as base material, production method, and test method on the antibacterial activity of WO need to be studied in detail. Figure 11(c) also shows the inhibition zone of 100%PLA and it is obvious that the base PLA does not have any antibacterial behavior.

3.8 *p*H Analysis of Structures

It has been discussed that the surface *p*H of a wound area has a critical role during the wound

Table 3 — Tensile properties and thickness

Samples wt. % WO	Vertical tensile stress, MPa	Horizontal tensile stress, MPa	Thickness mm
0	6.46	6.35	0.178
0.5	6.44	6.32	0.161
1	6.39	6.29	0.152
3	6.36	6.25	0.143

healing. Mainly, it controls the risk of infection as well as increases the antimicrobial activity. The previous study showed that an acidic environment created by the use of acids, algin, ethanoic acid, boric acid, vitamin C, and mucopolysaccharide helps in wound healing[23]. In this study, *p*H value range of the tested solutions were 5.72-5.13. The solutions are found to be acidic and it can be suggested that the developed structures' *p*H values can facilitate the wound healing process. The pH changes of all tested samples were observed between 4 and 5 days. After the treatment, the nano-structured wound dressings were only slightly dissolved in the pH test solution.

3.9 Tensile and Thickness Properties of Structures

These tests were carried out to examine the effect of WO addition on the thinness and the strength properties of the structures (Table 3). These tests were carried out to examine how the addition of WO affects the thinness and strength properties of the structures. MITUTOYO brand 547-401 model thickness comparator was used to determine the thickness of nanostructures after 2 h of production period. It is found that the addition of WO reduces the thickness of the structures. This may be due to the oily structure which leads to the closer orientation of fibre and Fig. 10 supports this assumption of reduced thickness. Another important finding here is that WO addition has no noteworthy effect on strength properties.

4 Conclusion

In this study, nanofibrous structures were developed with wool oil (lanolin) in order to slow the rapid water absorption and dispersion of PLA, thus preventing the wound to remain slightly dry. As it is known, dry wounds cause prolonged wound healing time. In liquid absorption and wicking tests, it was clearly seen that, as the oil ratio increases, the liquid dispersion decreases. This will help to keep the wound moist. When the microscope images of the final products were examined, it was seen that the fibrous structures were formed properly. This is considered as an important property as the air circulation and permeability is beneficial for wound healing process. The other beneficial properties of lanolin can be thought to develop smart wound dressings. This is a preliminary study which aims to show that wool oil and PLA can be spun into a nanofibrous structure by using electrospinning technique.

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References

1 Gündüzalp A A & Güven S, *Waste, Types, Waste Management, Recycling and Consumer: Çankaya Municipality and Neighborhood Consumers* (Hacettepe Üniversitesi Sosyolojik Araştırmalar E-Dergisi), 2012.

2 Eser B, Çelik P, Çay A & Akgümüş D, Sustainability and Recycling Opportunities in the textile and apparel sector, *TMMOB Tekstil Mühendisleri Odası Tekstil ve Mühendis*, 23 (101) (2016) 43-60.

3 Romero-Garay M G, Montalvo Gonzalez E, Hernadez-Gonzalez C, Soto-Dominguez A, Becerra-Verdin E M & Garcia-Magana MDL, Bioactivity of peptides obtained from poultry by-products: A review, *Food Chem: X*, 13 (2022) 100181.

4 Sidraa Q, Tabasum S, M Zia Khalid, Parveen B & Hussain M T, A novel water borne green textile polyurethane dispersions finishes from cotton *(Gossypium arboreum)* seed oil based polyol used in modification of cellulosic fabrics, *Carbohydrate Polym Technol Appl*, 2 (2021) 100170.

5 López-Mesasa M, Christoeb J, Carrilloa F & Crespi M, Supercritical fluid extraction with cosolvents of wool wax from wool scour wastes, *J Supercritical Fluids*, 35 (2005) 235-239.

6 Jacob S, The lanolin-wool wax alcohol update, *Consultant 360*, 54 (2014) 303-304.

7 Uzun M, Diana A & Gunduz O, 3D-Printed lanolin-based sodium alginate wound dressings, *Engineering Materials for Stem Cell Regeneration*, edited by Sheikh F (Springer Nature), 2020.

8 Alzaga R, Pascual E, Erra P & Bayona J M, Development of a novel supercritical fuid extraction procedure for lanolin extraction from raw wool, *Analytica Chimica Acta*, 381 (1999) 39-48.

9 Lindley H, The chemical composition and structure of wool, in *Chemistry of Natural Protein Fibers*, edited by RS Asquith (Springer, Boston), 1977.

10 Ash M & Ash I, *Handbook of Pharmaceutical Additives*, (Gower Press, UK), (1995) 576.

11 Mariani C N, Albuquerque R S, Souza S C, Giesta RO, Fernandes APS & Mondin B, Comparative study of the use of HPA lanolin and breast milk for treating pain associated with nipple trauma, *Rev Bras Ginecol Obstet*, 40 (11) (2018) 664-672.

12 Guo Y, Zheng Y, Qui S & Zeng A, Metal lanolin fatty acid as novel thermal stabilizers for rigid poly(vinyl chloride), *J Rare Earths*, 29 (5) 2011 401-406.

13 Infante VHP, Lohan SB, Schanzer S, Campos PM BGGM, Ledemann J & Meinke MC, Eco-friendly sunscreen

formulation based on starches and PEG-75 lanolin increases the antioxidant capacity and the light scattering activity in the visible light, *J Photochem Photobio B: Biology*, 222 (2021)112264.

14 Oliveira FS, Vieira F Guimaraes JV Aredes NDA & Campbell SH, Lanolin and prenatal health education for prevention of nipple pain and trauma: Randomized clinical trial, *Enfermería Clínica (English Edition)*, 31 (2) (2021) 82-90.

15 Chvapil M, Gaines JA & Gilman T, Lanolin and epidermal growth factor in healing of partial- thickness pig wounds, *J Burn Care Rehabil*, 9 (3) (1988) 279-284.

16 Wade A & Weller PJ, *Handbook of Pharmaceutical Excipient*s, (The Pharmaceutical Press, London), 1994, 262.

17 So H Mui, Lee CCH, Hung AK, et.al., Comparing the effectiveness of polyethylene covers (Gladwrap™) with lanolin (Duratears®) eye ointment to prevent corneal abrasions in critically ill patients: A randomized controlled study, *Int J Nurs Studies*, 45 (11) (2008) 1565-1571.

18 İşmal ÖE & Yıldırım ve L, Environmentally Friendly Approaches in Textile Design, *Akdeniz Sanat Dergisi*, cilt 4 (8) (2013).

19 Uzun M, *Development of Novel and Responsive Structures for Wound Management Incorporating Gelling Materials*, PhD. Thesis, The University of Bolton, 2012.

20 Karen JP, Pavezi A, Rocha A, Bonaféa G, Electrospinning-electrospraying of poly(acid lactic) solutions in binary chloroform/formic acid and chloroform/acetic acid mixtures, *J Molecular Liquids*, 320 Part B (2020) 1144-1148.

21 Singhal P, Preparation and characterization of poly (E-CAPROLACTONE) nano fibers by electrospinning technique for tissue enginerring applications, *Materialstoday Proceedings*, 37 Part 2 (2021) 2497-3001.

22 Douglas HE & Wood F, Burns dressings, *Aust Fam Physician*, 46 (3) (2017) 94-97.

23 Nagoba BS, Suryawanshi NM, Wadher B & Selkar S, Acidic environment and wound healing: A review, *Wounds*, 27 (1) (2015) 5-11.