PATCH FABRIC DESIGN FEATURING NATURAL OIL-FUNCTIONALIZED NANOFIBER COATING FOR DRY SKIN

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ABSTRACT: *Dry skin is a common dermatological condition that results from the disruption of the skin's moisture balance, often accompanied by symptoms such as itching, flaking, and sensitivity. This study aims to develop and evaluate the effectiveness of fabric patches functionalized with nanofibers containing natural oils, which can be easily attached to the inner surfaces of garments.*
Coconut, St. John's wort, and lavender oils are well-known for their beneficial effects in skincare. These oils were incorporated into thermoplastic polyurethane (TPU) nanofibers and coated onto fabric surfaces. The opposite side of the fabric patches was equipped with skin-friendly, pressure-sensitive adhesive bands, allowing the patches to adhere securely to the inner surfaces of various garments. This design enables users to place the patches over areas of dry skin as needed and replace them when necessary.
It is expected that nanofibers functionalized with these natural oils will have a positive impact on alleviating skin dryness. In this preliminary study, general information is provided about coconut, St. John's wort, and lavender oils, as well as nanofibers functionalized with natural oils and their potential applications. The fabrication of TPU nanofibers functionalized with coconut oil and their integration into fabric patch form are also presented. The functionalized nanofibers were characterized by scanning electron microscopy (SEM), water contact angle measurement, and oil release characteristic. As a result, the developed patches are proposed as functional medical textile materials with potential application in soothing dry skin.

Keywords: *Coconut oil, nanofibers, skin dryness, functional nanofiber patches.*

DIZAJN PATCH TKANINE SA NANOVLAKNASTIM PREMAZOM FUNKCIONALIZOVANIM PRIRODNIM ULJIMA ZA TRETMAN SUVE KOŽE

APSTRAKT: *Suva koža je uobičajeno dermatološko stanje koje nastaje usled narušene ravnoteže vlažnosti kože, a često je praćeno simptomima kao što su svrab, perutanje i osetljivost. Ova studija ima za cilj razvoj i evaluaciju efikasnosti flaster tkanina funkcionalizovanih nanovlaknima sa prirodnim uljima, koje se mogu lako pričvrstiti za unutrašnje površine odeće.*

Kokosovo ulje, kantarionovo ulje i ulje lavande poznata su po svojim blagotvornim efektima u nezi kože. Ova prirodna ulja su inkorporirana u termoplastični poliuretan (TPU) nanovlakna i naneta na površinu tkanine. Suprotna strana tkanine je opremljena koži prijemčivim, na pritisak osetljivim lepljivim trakama, koje omogućavaju sigurno prijanjanje za unutrašnje površine različitih odevnih predmeta. Ovakav dizajn omogućava korisnicima da flastere postave na područja kože sa izraženom suvoćom i po potrebi ih zamene.

Očekuje se da nanovlakna funkcionalizovana ovim prirodnim uljima imaju pozitivan efekat u ublažavanju simptoma suve kože. U ovoj preliminarnoj studiji data je opšta informacija o kokosovom, kantarionovom i ulju lavande, kao i o nanovlaknima funkcionalizovanim prirodnim uljima i njihovim potencijalnim primenama. Prikazana je izrada TPU nanovlakana funkcionalizovanih kokosovim uljem i njihova integracija u oblik tkanih flastera. Funkcionalizovana nanovlakna su karakterisana pomoću skaning elektronske mikroskopije (SEM), merenja kontaktnog ugla vode i profila oslobađanja ulja. Kao rezultat, razvijeni flasteri se predlažu kao funkcionalni medicinski tekstilni materijali sa potencijalnom primenom u ublažavanju suve kože.

Ključne reči: *Kokosovo ulje, nanovlakna, suva koža, funkcionalni nanovlaknasti flasteri.*

1. INTRODUCTION

The term 'xerosis' or 'dry skin' is commonly used by doctors, patients, and the cosmetic industry to describe skin that feels rough, flaky, cracked, and lacking moisture. It is often linked to atopic skin conditions and mild forms of ichthyosis vulgaris [1]. Dry skin is a common dermatological condition that results from the disruption of the skin’s moisture balance, often accompanied by symptoms such as itching, flaking, and sensitivity. Dry skin often results from a mix of factors, including genetic background, environmental conditions, age, and ethnic differences [2]. Managing dry skin typically involves the use of emollients. An ideal emollient is suggested to include five essential components: humectants, non-physiological lipids (such as mineral or vegetable oils), physiological lipids (like ceramides and free fatty acids), soothing or anti-itch agents, and ingredients that promote epidermal differentiation [2].

Natural plant-based oils (fixed and essential oils) are widely used around the world as topical treatments due to their affordability and easy accessibility. Many of these oils contain active compounds with antimicrobial, antioxidant, anti-inflammatory, and antipruritic effects, making them appealing as alternative or complementary options in the management of xerotic and inflammatory skin conditions linked to barrier dysfunction [3]. There are several techniques for obtaining oils, including cold pressing for unrefined oils, heat or chemical distillation for essential oils, and the use of synthetic additives to create fragranced oils. Among these, the extraction and refinement method significantly influence the oil's suitability for skin care. Fixed oils—also known as carrier oils—which are non-volatile triglyceride-based compounds derived from plant or animal sources. Cold pressing is generally favored, as it avoids heat and chemicals, helping to retain beneficial lipids while minimizing the formation of potentially irritating byproducts [3-5].

In contrast, essential oils are volatile natural compounds extracted from various parts of plants, such as leaves, flowers, seeds, roots, or bark [5] generally through steam distillation or cold pressing. While fixed oils are composed of triglycerides, essential oils mainly consist of terpenoids, phenolics, polyacetylenes, and phthalates. Due to their low boiling points and tendency to evaporate at room temperature, they are termed "volatile oils." Microencapsulation of essential oils has enabled their application in pharmaceutical and biomedical fields. The incorporation of essential oils into polymeric nano- and microfibers offers novel approaches in biomedical applications such as wound dressings, tissue engineering scaffolds, and controlled/targeted drug delivery. Like fixed oils, essential oils are hydrophobic and soluble in organic solvents, although their polarity can vary [5].

The ability to be functionalized is one of the key advantages of nanofiber-based materials, enabling their application across a broad range of fields. A variety of active agents—such as antibacterial, moisturizing, or therapeutic compounds that support wound healing—can be incorporated into nanofibers. Natural oils, including coconut oil, St. John's wort oil, and lavender oil, may also serve as active agents. Nanofibers loaded with these natural oils can be engineered into patch-like systems with an adhesive layer, allowing for easy application to the skin and providing relief from dryness.

One such example is coconut oil (Cocos Nucifera oil), a natural moisturizer effective in relieving dry skin. Its medium-chain fatty acids, particularly lauric acid, help maintain the skin's moisture balance and reduce transepidermal water loss (TEWL), keeping the skin hydrated. It also exhibits anti-inflammatory and antioxidant properties that soothe sensitive or irritated skin [6, 7]. Coconut oil typically appears as a white or light-yellow to orange semi-solid substance. It has a density of approximately 0.92 g/cm³ and is insoluble in water. Coconut oil is non-toxic and primarily consists of glycerides of myristic, palmitic, stearic, oleic, and linoleic acids [8]. Scientific studies indicate that coconut oil strengthens the skin barrier and is as effective as mineral oils in moisturization. Mohamadi et al. encapsulated coconut oil into blend nanofibers of PCL, a hydrophobic synthetic polymer with high mechanical properties, and Gel, a natural, biocompatible, biodegradable, and hydrophile polymer as a potential wound dressing candidate [9]. They also investigated in vivo wound healing property of coconut oil loaded nanofiber/hydrogel hybrid scaffold in anothor study [10]. Jaganathan et al. produced coconut oil loaded polyurethane nanofibers for vascular graft applications [11].

St. John's Wort oil (Hypericum perforatum oil) is a natural essential oil with strong healing and moisturizing effects on the skin. Components such as hypericin, flavonoids, and essential fatty acids support the skin barrier, reduce dryness, and maintain skin hydration. Its anti-inflammatory and cell-regenerating properties help soothe irritated and stretched skin [12, 13]. Research has shown that St. John's Wort oil promotes epithelial regeneration and accelerates wound healing [14], making it a promising natural option for moisturizing and improving skin elasticity. Sivri and Sakarya used St. John's Wort oil and some other extracts with polyethylene oxide (PEO) and polyvinyl alcohol (PVA) polymers, produced nanofiber membranes by electrospinning and investigated their use as wound dressing materials [15]. Arik et al. reported the production of St. John's Wort oil, lavender oil, and virgin olive oil loaded thermoplastic polyurethane [16].
Lavender oil (Lavandula angustifolia) is also widely used natural essantial oil in skincare due to its antiseptic, anti-inflammatory, and soothing effects [17]. In addition to being effective against dryness, it can relieve irritation and support the healing process. Lavender oil enhances skin hydration and strengthens the skin barrier, providing relief particularly for dry and stretched skin. It may also support skin elasticity and prevent stretch marks by improving blood circulation. Its antibacterial and antifungal activities also contribute to a faster healing process, making it a natural and effective remedy for skin dryness and related discomfort. Several researchers [18-20] were also used lavender oil in electrospinning for various biomedical purposes.
Nanofibers are commonly produced by the electrospinning method. In this technique, a high-voltage power supply, a syringe (nozzle) containing the polymer solution, and a collector area are used. The potential difference between the nozzle and the collector stretches the polymer solution, forming a fine jet that travels toward the collector. During this process, the solvent evaporates, and extremely fine nanofibers accumulate on the collector [21]. Surfaces of electrospun fibers possess a high surface area compared to conventional film-forming methods and exhibit high porosity and small pore sizes, closely resembling the native extracellular matrix (ECM) [22].
Incorporating fixed oils like coconut oil into nanofibers presents a promising alternative approach for skin therapy. Nanofibers can act as an effective carrier matrix for these oils, providing a novel and efficient delivery system for topical application. Besides, the controlled release of essential oils from nanofibers may help mitigate their potential cytotoxic effects on human cells. Furthermore, essential oils gain increased stability in these nanofiber systems, extending shelf life and supporting commercialization. Studies have focused on overcoming the limitations of essential oils such as volatility, low stability, and sensitivity to environmental factors, while also evaluating their biological effects [23]. Findings show that integrating essential oils into engineered biomaterials enhances antibacterial activity, biocompatibility, and wound healing. The combination of biomaterials with fixed and essential oils presents a promising strategy for creating advanced hybrid biomedical systems capable of delivering natural therapeutic agents
This study aims to develop and evaluate the effectiveness of fabric patches functionalized with nanofibers containing natural oils, which can be easily attached to the inner surfaces of garments by pressure-sensitive adhesives (PSAs). PSAs have become integral

components in medical and drug delivery systems due to their unique properties that allow for gentle yet effective adhesion to the skin and other biological surfaces [24, 25]. These adhesives form a bond when light pressure is applied, without requiring solvents, heat, or water for activation, making them ideal for sensitive and delicate applications [26]. In medical devices, PSAs are widely used in wound dressings, transdermal patches [27], and wearable sensors [28], where secure attachment and patient comfort are paramount. Their ability to conform to irregular skin surfaces ensures sustained contact, which is critical for effective drug absorption and monitoring. Moreover, the biocompatibility and hypoallergenic nature of medical-grade PSAs reduce the risk of skin irritation and allergic reactions, supporting long-term use. Advances in PSA formulations have also enabled controlled drug release profiles when integrated into transdermal systems, enhancing therapeutic outcomes [28, 29]. The selection of an appropriate PSA depends on factors such as adhesion strength, peel resistance, moisture permeability, and compatibility with both the drug and the skin.

In this preliminary study, the fabrication of TPU nanofibers functionalized with coconut oil and their integration into a fabric patch form are presented. The functionalized nanofibers were characterized using scanning electron microscopy (SEM) and water contact angle measurements. Additionally, a simple gravimetric oil release test was conducted to quantify the amount of oil transferred to a piece of paper. As a result, the developed interchangeable patches are proposed as functional medical textile materials with potential applications for relieving dry skin. These patches are designed for limited-period use and should be replaced with a new one after a certain application time.

2. MATERIALS AND METHODS

2.1. Materials

For the electrospinning process, TPU material, Pellethane® 2103-80AE, composed of 4,4'-methylenebis (phenyl isocyanate), polytetramethylene oxide, and 1,4-butanediol, was utilized. This TPU was supplied by Velox on behalf of Lubrizol Advanced Materials. The solvent N,N-dimethylformamide (DMF) was sourced from Sigma-Aldrich. Cold-pressed Life In brand coconut oil, with a melting point of 24 °C, was locally sourced. Henkel AQUENCE, water-based PSA was used to form an adhesive layer. A non-stick paper was used to cover this adhesive layer. Whatman filter papers were used to analyze the gravimetric oil release behavior.

2.2. Method

A polymer solution with a concentration of 9 and 10% TPU was prepared based on insights from earlier research [Oğlakcıoğlu et al. 2021]. TPU granules were dissolved in DMF at ambient temperature. Coconut oil was added at amounts corresponding to 100% and 200% of the polymer weight, and mixing was continued until a homogeneous mixture was obtained. The samples were coded as 100CO-10TPU, 100CO-9TPU, and 200CO-9TPU. In the sample codes, 'CO' refers to the amount of coconut oil added relative to the polymer weight, and 'TPU' indicates the polymer content (g) in the solution. For example, 100CO-10TPU represents a sample containing coconut oil at 100% of the polymer weight and 10 g of TPU.

Electrospinning was performed using a system that included a 10 mL syringe equipped with a 2.5 cm long, 22-gauge flat-tip needle, a grounded electrode, and a high-voltage power supply (Pulselectronic, 20 kV DC output). The process was carried out under an applied voltage of 13 kV, with the distance between the needle tip and the collector set at 18 cm, and a flow rate of 2 mL/h. As the collector, a rotating grounded metal drum wrapped in jersey fabric pre-treated with Henkel's Aquence was used for fiber deposition.
The bottom side of the fabric was also coated with Henkel's Aquence and covered with a non-stick protective release liner to preserve its adhesiveness until use.

2.3. Characterization

Morphology of the samples was characterized by scanning electron microscopy (SEM, Phenom Prox G6 instrument). Each sample was coated with thin film of gold using Emitech K550X ion sputtering device at 15 mA and $8x10^{-2}$ mbar vacuum for 2 minutes.
The wettability characteristic of the coconut oil loaded TPU nanofiber membrane was assessed by measuring the water contact angle (WCA) using a CAM 200 contact angle goniometer (KSV Instruments, Helsinki, Finland). The measurement wa carried out on the top surface of the electrospun membranes using distilled water at ambient conditions (25 °C, 40–50% relative humidity). A 2 µL water droplet was carefully dispensed from a height of 5 cm onto the membrane surface through a vibrating micro-syringe. After 15 seconds of stabilization, the droplet was observed for a duration of 2 minutes to ensure that no significant deformation or absorption took place.
To characterize the oil release behavior of the coconut oil-loaded TPU nanofibers, a gravimetric method was employed. A piece of Whatman filter paper was placed on top of the prepared nanofiber patch and incubated at 37 °C. At predetermined time intervals (1 h, 3 h, 5 h, 8 h, 24 h, 28h, 36h and 48h), the filter paper was weighed to determine the cumulative amount of oil transferred from the nanofibers.

3. RESULTS AND DISCUSSION

SEM images of 100CO-10TPU, 100CO-9TPU and 200CO-9TPU nanofibers at two different magnifications. The images clearly show a dense oil coverage on the nanofiber surfaces. While nanofiber formation was achieved for 100CO-10TPU, the fiber structure was almost lost in 200CO-9TPU. In the case of 100CO-9TPU, coconut oil was extensively distributed across the fiber surfaces and appeared to fill the inter-fiber gaps.

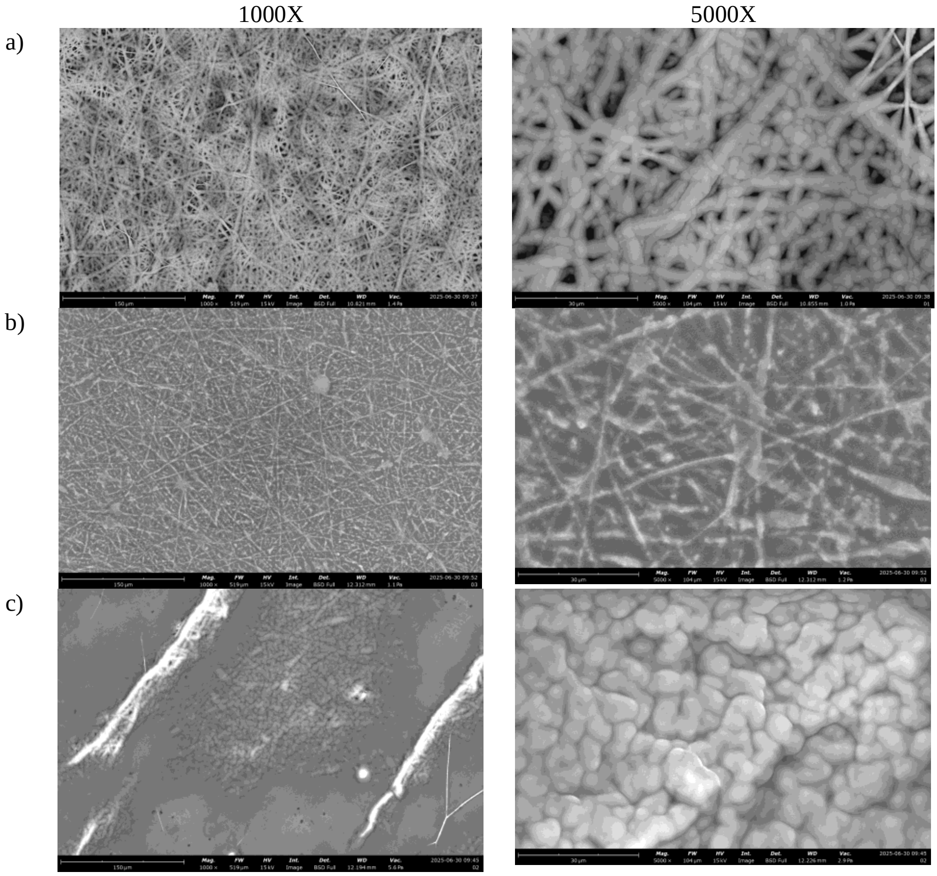

Figure 1: SEM images of 1000X and 5000X magnification of a) 100CO-10TPU, b)100CO-9TPU and c) 200CO-9TPU nanofibers

The water contact angle (WCA) between the water droplet and the sample was measured for 100CO-10TPU nanofibers, and the corresponding image (Figure 2) was captured after 15 seconds. The average WCA value, calculated from the right, middle, and left positions of the droplet, was determined to be 103°. Since the WCA of the sample exceeded 90°, it can be classified as hydrophobic.

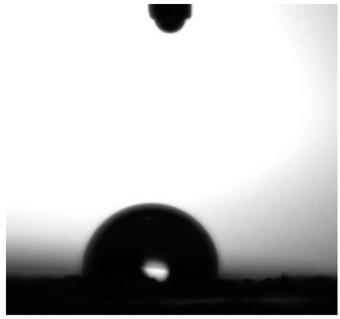

Figure 2: WCA image showing a contact angle of 103° for coconut oil-loaded TPU nanofibers

The release characteristics of coconut oil from the TPU nanofibers were shown in Figure 3. Coconut oil loaded nanofibers were placed with two paper pieces. The initial weight of the coconut oil-loaded nanofibers was recorded. At time intervals of 1 h, 3 h, 5 h, 8 h, 24 h, 28 h, 36 h, and 48 h, the samples were weighed, and the released amount of coconut oil was calculated relative to the initial coconut oil contentIt was observed that the release ratios of 100CO-9TPU and 100CO-10TPU samples were similar, both reaching approximately 40% of the total coconut oil content. When the initial loading of coconut oil was increased to 200% of the polymer weight, the total release ratio increased to approximately 60% of the initial loading. None of the samples released all of their oil content. However, it should be noted that the actual amount of coconut oil in the samples was not directly measured; instead, it was theoretically calculated based on the final weight of the samples. Representative images of the nanofibers and the oil stains on the white papers are presented in Figure 4. The oil stains released from the nanofibers were clearly visible in the presented images.

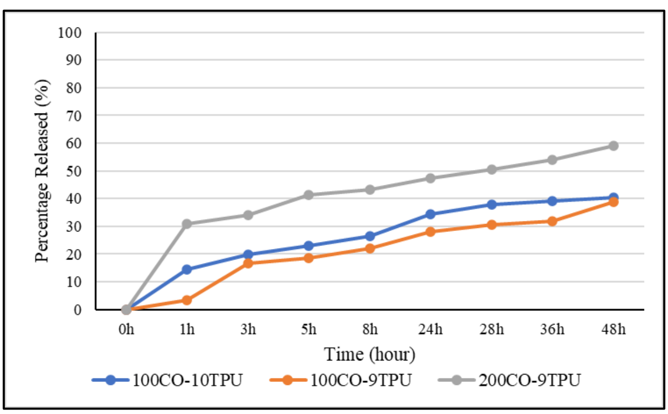

Figure 3: Percentage release of coconut oil-loaded 100CO-10TPU, 100CO-9TPU and 200CO-9TPU nanofibers

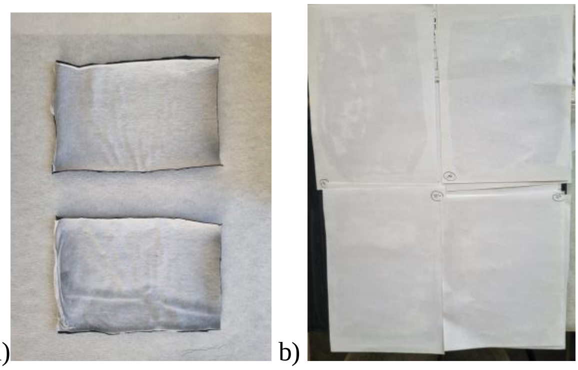

Figure 4: Representative images of coconut oil loaded TPU nanofibers samples and oil-stained white papers

4. CONCLUSION

In this study, thermoplastic polyurethane (TPU) nanofibers functionalized with natural oils such as coconut oil were successfully fabricated and characterized. The morphological analysis revealed that the nanofiber structure was maintained at moderate oil loadings; however, excessive oil content led to a loss of fiber integrity. The oil release studies demonstrated that the amount of oil released increased with higher initial loading, yet complete release was not achieved, indicating a sustained release potential. Additionally, water contact angle measurements confirmed the hydrophobic nature of the functionalized nanofibers, which is beneficial for creating a protective barrier on the skin. The visual inspection of oil stains further supported the release behavior of the coconut oil from the nanofiber structures. Overall, the developed coconut oil-loaded nanofiber patches offer a promising approach as functional medical textile materials with potential applications in alleviating skin dryness. Future studies will focus on optimizing oil loading levels, assessing the long-term release profiles, and evaluating the biocompatibility and therapeutic efficacy of these patches

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