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SKIN TEMPERATURE AND MOISTURIZING EFFECTS OF FILMS WITH PHASE CHANGE MATERIALS, ERYTHRITOL, AND COCONUT OIL

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Abstract

To explore ways to protect dogs' paw pads from hot asphalt in the summer and snow removal chemicals in winter, a film was created by adding erythritol, a sugar alcohol that has a moisturizing effect and is a phase-changing material that undergoes an endothermic reaction when it changes from a solid to a liquid, and coconut oil, which is often used as a moisturizer, to a pullulan solution.
When 15g of erythritol was evenly mixed with 50 mL of water, the temperature of the water decreased by 8 ℃, and when the coconut oil melted, the temperature decreased by 2.63 ℃. By utilizing the properties of these substances, a film was created. First, when a film was created using a ratio of 1/10 of erythritol (g):1% pullulan solution (mL), due to crystallization, it was difficult to maintain the shape of the film. When this film was dropped in water, it reduced the temperature by 8% more than the pullulan film, but when it was mixed with coconut oil, the temperature reduction wasn't much different. To stabilize the film, the erythritol content was reduced, and the pullulan content was increased. The results of adding 1g and 3g of erythritol to 1% and 3% of 100mL pullulan solution showed that the 1g erythritol film was much more stabilized than the 3g erythritol film. When the films were dissolved in water, the 1g erythritol film didn't show much effect, but the 3g erythritol film had a 2% temperature reduction in comparison to the pullulan film. Moreover, because the film dissolved more slowly if the density of the pullulan solution increased, the 3% pullulan film with erythritol dissolved more slowly than the 1% film, resulting in the 1% film showing a greater reduction in temperature. When coconut oil and sodium alginate were added to these films, the films were stable but showed no cooling effect. Because the 1% pullulan solution with 1g of erythritol was the most stable film, it was used as a model for the furtherance of other films. Through experimenting with the surface temperature of pig skin by comparing the temperature increase with the control, which was with no film, the film made with erythritol and coconut oil showed a 6% decrease in temperature compared to the control, and the moisture content increased by 70%. Therefore, using erythritol and coconut oil can effectively moisturize and reduce temperatures. Because it is a type of film, it is convenient and easy to use and can reduce the surface temperature of dogs' paws, something that prior moisturizers couldn't do. Therefore, this film can be seen to effectively treat the damages inflicted upon dogs due to outside activity in extreme conditions.

Keywords: *Dog's paw, erythritol, coconut oil, Pullulan film, PCM(Phase change materials).*

Introduction

In recent years, South Korea has witnessed a significant growth in pet ownership, specifically of dogs. According to a 2024 Korea Times article, for the past 5 years, from 2018 to 2023, the percentage of households with pets increased by 4.5%, reflecting a societal shift toward viewing pets as animals and family members. With a record high of 28.2% of households with pets, the pet industry in South Korea reached 5.35 trillion won as of 2025. With the increase in dog ownership and more outdoor activities, it's becoming more common for dogs to suffer damage

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to their paws. According to the American Kennel Club, dogs' paws can be burned by hot pavement during the day in summer or by snow-melting agents during the winter months. Paw and toe damage can also be caused by friction against the pavement. Because dogs use their tongues and paw glands to regulate body temperature and their digital pads and palmar pads, which cover a large area of the paw, to absorb shock when moving, paw burns, skin irritation, and other damage to the paws are important for their health [1, 2]. To protect the pads, dog owners use special shoes or moisturizers to reduce damage. To find out how to reduce the surface temperature of the paw pads, which are heated by outdoor activities, while increasing moisture content, we decided to use phase-changing materials, which have the property of melting and absorbing heat and changing from solid to liquid when the temperature rises, or releasing heat and returning to solid when the temperature decreases [3]. We decided to use erythritol and coconut oil as phase-changing materials that moisturize the paw. First, erythritol, a sugar alcohol, is about 70% sweeter than sugar. When dissolved in water, it has an endothermic reaction that lowers the temperature, which is also the reason why it is used to create a refreshing effect on candies. Erythritol also has low hygroscopicity, easily forms crystals, is stable to heat and acid, and has a solubility of about 38% in a saturated solution at 20°C [4, 5]. As a phase-changing substance, erythritol has also been shown to be effective in inhibiting bacteria associated with tooth decay and is harmless when tested for oral toxicity in one-year-old dogs [6, 7]. Erythritol is commercially available as a moisturizer, but there are minimal studies on its ability to moisturize skin and reduce temperature. In addition, coconut oil remains solid at 21~23°C and melts at about 25°C [8]. When coconut oil was applied to the headliner structure of a car (Toyota Cressida) using this property, as the car cabin temperature decreased by 15 °C on average, coconut oil showed its significance as a phase-changing material capable of mediating temperature [9]. It also has antibacterial, moisturizing, and wound-healing properties, in addition to atopy, when ingested and applied to dogs suffering from atopic diseases, it can reduce the Immunoglobulin E associated with atopic diseases [10,11]. The two substances were mixed to formulate a film with pullulan to make it easy to apply to the dog’s paws at any time. Pullulan is a polysaccharide produced by strains of A. pullulans that is tasteless, odorless, and highly soluble in water [12]. Because it is non-toxic, it is utilized as a biodegradable and eco-friendly food packaging and coating material. It is also used in cosmetics formulations such as creams, lotions, shampoos, and packs, and when it is made into a film, its properties change when the relative humidity becomes 80%. It also has the property of melting, which must be considered when making the film. Therefore, the study made a film mixing erythritol, coconut oil, and pullulan solution, which are phase-changing materials that increase moisture content, and chose the perfect ratio between erythritol and coconut oil to make a film that dissolves well in water and reduces temperature effectively. Lastly, by observing the film dissolving in water and changing the surface temperature, the study used pig skin to see if the film can reduce surface temperature and increase moisture content.

Materials and Methods

The Change in temperature pn the amount of erythritol and coconut oil

Checked how much the temperature drops depending on the amount of erythritol and coconut oil, which are phase change substances. In Fig. 1.1, after adding 1, 5, 10, and 15g of erythritol (Jungbunzlauer S.A.) to 50 mL of water in an Erlenmeyer flask, the lowest temperature was measured using a temperature sensor (Arduino Thermal Probe: Ds18B20). Coconut oil dissolves at 24°C and hardens below that temperature, so 15g of coconut oil was placed in a conical tube and placed in a 40°C water bath to measure the temperature change of the oil in Fig. 1.2.

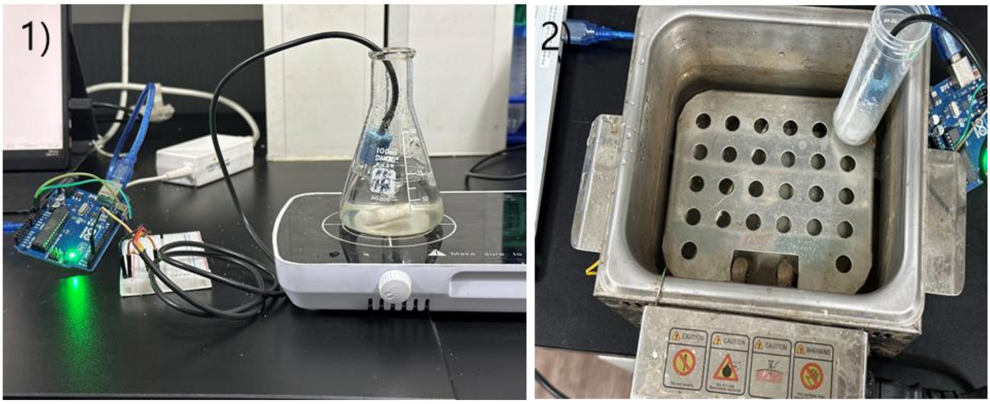

Fig. 1. Temperature change when erythritol and coconut oil are dissolved 1) Place an Arduino temperature sensor in the flask with erythritol to watch the temperature change 2) Place a conical tube with coconut oil in a water bath to watch the temperature when the coconut oil starts to melt from solid to liquid with the sensor

Production of pullulan, erythritol, and coconut oil mixed film and temperature change

Erythritol, a substance that decreases the temperature when dissolved in water or at a constant temperature, and pullulan, a material that can dissolve coconut oil in water, were used to make a film. The concentration of pullulan was set to 1% and 3%, and 1g of erythritol and 1g of coconut oil were added to 10 ml of the mixture. An infrared camera (FLIR i2) was fixed on a stand facing the petri dish. Then, 0.5 ml of water was added to the next petri dish, and the temperature change was recorded for 1 minute as seen in Fig. 2.

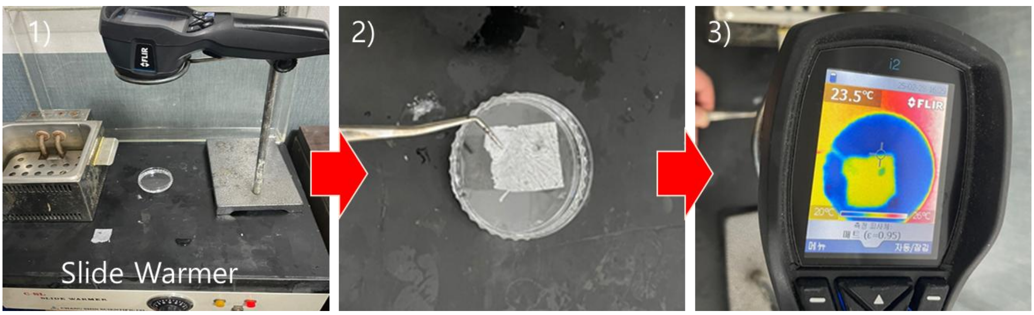

Fig. 2. Seeing the temperature change as the film dissolves 1) FLIR measurement of a petri dish with water on a slide warmer 2) placing the film in the petri dish with water 3) seeing the surface temperature as the film dissolves

Temperature changes due to the film depend on the amount of erythritol and the presence or absence of coconut oil and sodium alginate

A film was made by dissolving 0.3g and 0.6g of erythritol in 30 mL of 1% and 3% pullulan solution, adding 0.3g of coconut oil to this solution, and finally adding mL of 1% Sodium Alginate solution to ensure that the coconut oil and water were well mixed. Each film was cut into 3X3 cm pieces and placed in a Petri dish. Since the temperature may become irregular if water is poured right away, the petri dish was placed on a slide warmer where the surface temperature was maintained at 40°C. Then, 5 mL of water in a water bath set at 37°C was poured into this Petri dish. Then, temperature changes were observed using an infrared camera for 1 minute.

Temperature and moisture percentage of pig skin surface by PEC (Pullulan, Erythritol, Coconut) film

In the previous experiment, the film was made under the condition that the film would be well-formed and soluble in water. 40 mL of 1% pullulan solution with 0.4 g of erythritol, 0.4 mL of coconut oil, and 100 µL of lecithin (from Soybean, Samchun Chemical) as an emulsifier were mixed, dried, and used. As a substitute for human skin, pork skin (chilled on the day of production, Dodam Processing, preserving of meat and meat) was cut into 2X2 cm pieces [14]. To control and maintain a constant temperature, a thermoelectric device (TEC1-12708) was connected to a DC power supply device so that the surface temperature was 41 ~ 43 °C. In Fig. 3, a pork skin was placed on top of the thermoelectric device, and an infrared camera was fixed to it, and the surface temperature of the pork skin was measured after 5 minutes. After that, in Fig. 3b, the film was placed on top, sprayed with about 0.2 mL of water, and the surface temperature was measured again for 2 minutes at 5-second intervals. After the measurement, we divided the pork rinds into two groups: those that were left at room temperature for 5 minutes and those that were placed in a 50°C dryer for 5 minutes to see if each film helped retain moisture. The skin moisture was then measured using a skin tester (Golden Calf, H2B Co., LTD) that can measure flat surfaces.

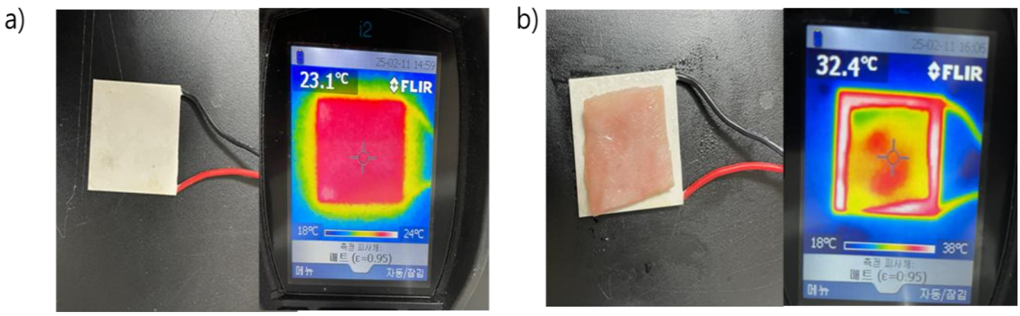

Fig. 3. a) Picture of the color temperature when the thermoelectric device is energized
b) Picture of the color temperature when a pork rind is placed on top of the thermoelectric device

Results and Discussions

The change in temperature depends on the amount of erythritol and coconut oil

In Fig. 4, as the amount of erythritol increased, the temperature of the water decreased rapidly, and the temperature difference began to decrease by about 3°C when 5 g of erythritol was dissolved in the water and decreased by about 8°C when 15g was added. When coconut oil was added to a water bath at a temperature of 40°C, the temperature of the oil decreased by 2.63°C from 38°C (Table 1).

Production of pullulan, erythritol, and coconut oil mixed film and temperature change

When 10 mL of 1% pullulan and 3% pullulan solutions were dried with 1 g of erythritol, 1 g of coconut oil, and coconut oil and erythritol simultaneously, the films shown in Fig. 5 were formed. First, 1% pullulan and 3% pullulan kept the film shape well during drying. When more coconut oil was added, it was observed that the coconut oil was cloudy and solidified on the surface. When pullulan and erythritol were mixed, crystals formed in the film, and the film broke. And when coconut oil and erythritol were added at the same time, the crystals also broke.

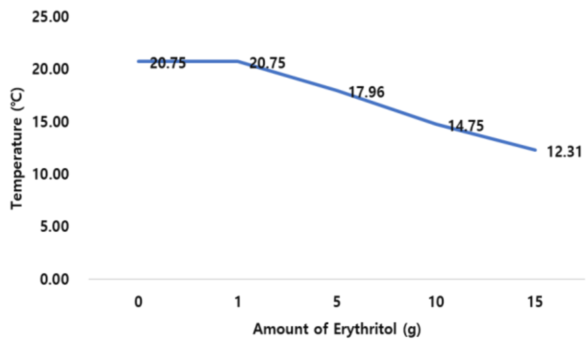

Fig. 4. Temperature change of water based on the amount of erythritol dissolved in water

Table 1. Temperature changes when coconut oil goes from a solid state to a liquid state

	trial 1	trial 2	trial 3	average
Temperature(℃)	35.19	35.55	36,31	35.37

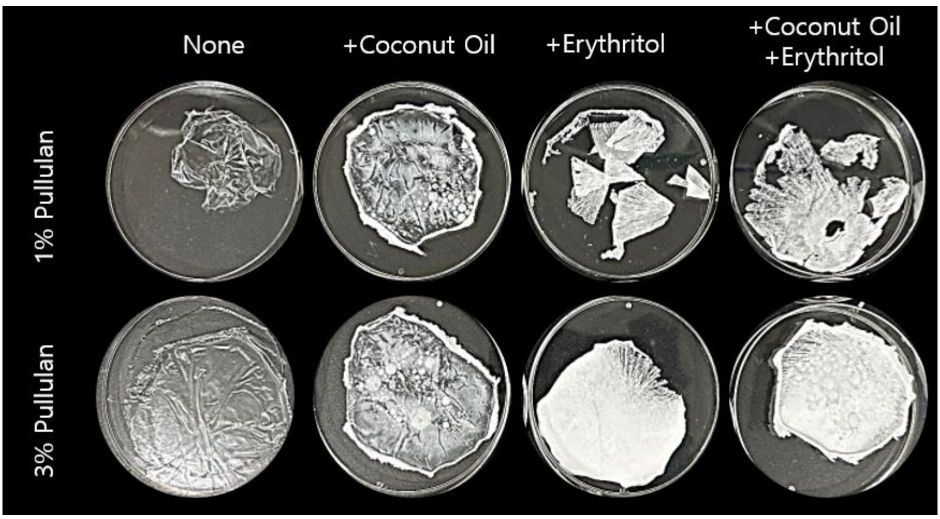

Fig. 5. A pullulan film is made by mixing different amounts of erythritol with coconut oil and sodium alginate

The temperature of the film surface was measured in 1 minute when 1 mL of water was dropped on the film formed in Fig. 5. A total of three repetitions were performed, and the average values were compared as shown in Table 2. As seen in Fig. 6, the temperature decreased to 22.2 and 22.51% for both 1% and 3% pullulan films, respectively. On the other hand, when erythritol was added to pullulan films, the temperature decreased by 28.44% for pullulan 1% solution and 27.27% for pullulan 3% solution, which is about 5-6% more than the control. However, when coconut oil was added, the temperature decreased by 14.88% and 15.56% in the 1% pullulan solution and 3% pullulan solution, respectively, compared to the control. For this reason, it was expected that the temperature of the film surface would not be lowered due to the low thermal conductivity of coconut oil, rather than the effect of lowering the temperature by dissolving coconut oil. For this reason, it was found that the effect of erythritol decreased when the film was made by mixing coconut oil and erythritol.

Table 2. Temperature changes when coconut oil goes from a solid state to a liquid state

	1% Pullulan		3% Pullulan	
	0 min	1 min	0 min	1 min
Control	36.73	28.57	37.30	28.90
C: Coconut oil	37.17	31.63	37.47	31.63
E: Erythritol	36.80	26.33	36.93	27.27
Both(C, E)	37.37	29.10	37.47	29.23

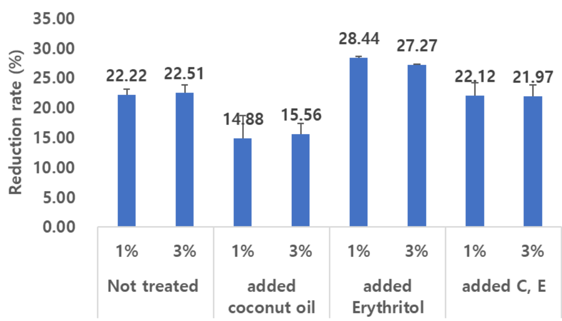

Fig. 6. The percentage decreases in temperature when films made with pullulan, coconut oil, erythritol, and a mixture of the two are placed in water.

Therefore, when we made the above film, we decided to reduce the concentration of erythritol to prevent the film from tearing due to the crystallization of erythritol, and we also decided to reduce the concentration of coconut oil. We also decided to use coconut oil as an ingredient to increase the moisturizing effect.

Temperature changes due to the film depend on the amount of erythritol and the presence or absence of coconut oil and sodium alginate

Erythritol was added to the 1% and 3% pullulan solutions to give a concentration of 1% and 3%. Then, a solution of coconut oil and sodium alginate was added at a ratio of 1/100 of the pullulan solution. As a result, the film made with pullulan solution alone was transparent and had a smooth surface, as shown in Fig. 7. However, when erythritol was added, the film became opaque because crystals were formed as the film dried. As the concentration of erythritol increased, it became more opaque, and the surface became rougher. When coconut oil and sodium alginate were added along with erythritol, no significant changes in the film were observed.

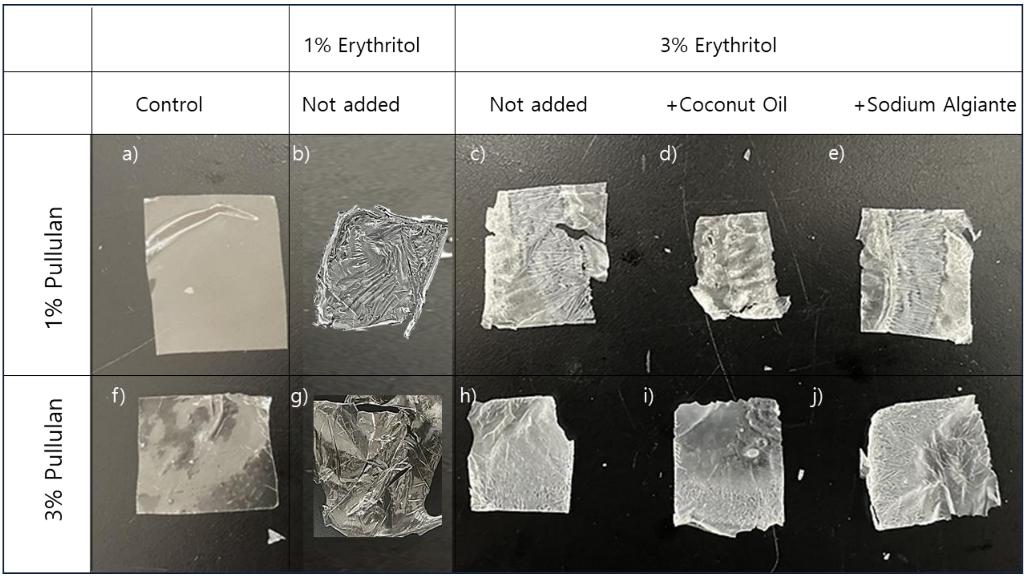

Fig. 7. Film made with pullulan, erythritol, coconut oil, and sodium alginate a) Film made from 1% pullulan solution, b) Film made from 1% erythritol in pullulan solution and then dried c) Film made from 3% erythritol in pullulan solution and then dried d) Film made from coconut oil added to make film in c) e) Film made from sodium alginate added to make film in c) f)) film made with 3% pullulan solution, g) film made with 3% erythritol in pullulan solution and then dried h) film made with 3% erythritol in pullulan solution and then dried i) film made with coconut oil when making the film in h) j) film made with sodium alginate when making the film in h)

Each film was placed in water to observe the change in the surface temperature of the water as it dissolved. Of the films made with erythritol in a 1% pullulan solution, the temperature of the water decreased the fastest when the film containing 3% erythritol was placed in the water compared to 1% erythritol. The combination of erythritol, coconut oil, and sodium alginate did not differ significantly from the 3% erythritol alone.

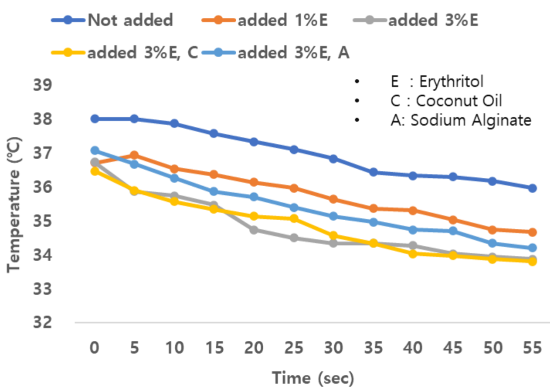

Fig. 8. Change in water temperature when a film made with 1% pullulan, erythritol, coconut oil, and sodium alginate is dissolved

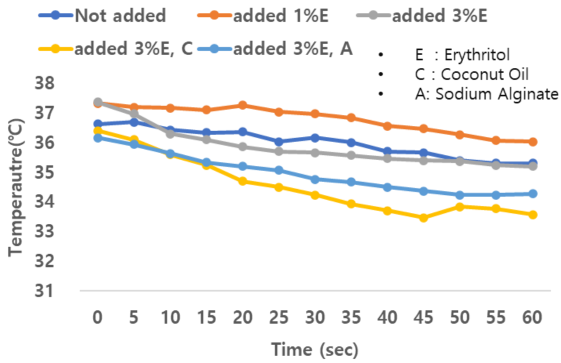

Fig. 9. Water temperature evolution of a film made with 3% pullulan, erythritol, coconut oil, and sodium alginate when dissolved in water

After calculating the percentage decrease in temperature over one minute, films were made by mixing erythritol, coconut oil, and sodium alginate in 1% pullulan and 3% pullulan solutions. The temperature reduction effect was better when the concentration of erythritol in 1% pullulan was increased from 1% to 3%, and the effect of mixing coconut oil and sodium alginate was not significant, as seen in Figures 8 and 9.

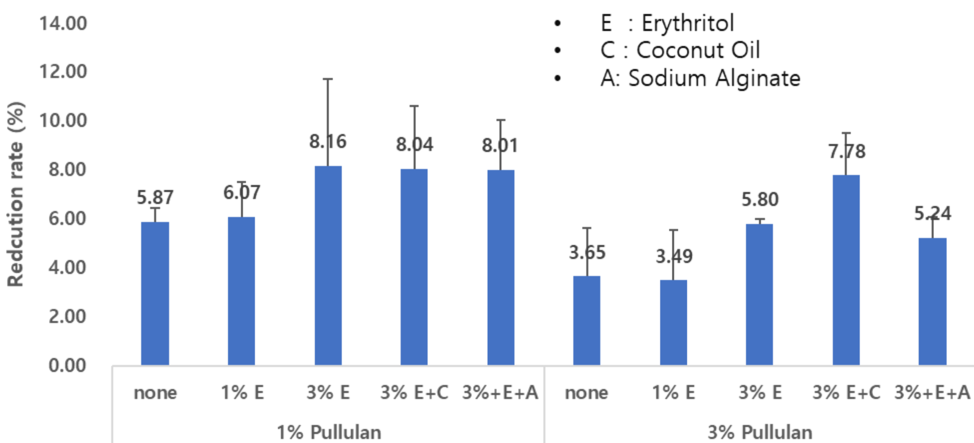

Fig. 10. Percentage decrease in water temperature when a film is made from a mixture of 1% pullulan, 3% pullulan, coconut oil, and sodium alginate are dissolved in water.

Therefore, we decided to use a 1% pullulan solution, which is a very soluble concentration, and add 1% erythritol, which makes the film thin and stable, to make the film. Instead of dissolving it in water, we decided to look at the temperature change on the surface of the pork skin.

Temperature and moisture percentage of pig skin surface by PEC (Pullulan, Erythritol, Coconut) film

Observing crystals of erythritol in a dried film

A 1% pullulan solution was mixed with erythritol, coconut oil, and lecithin, an emulsifier, respectively. As a result, crystals of erythritol were formed in the film when erythritol was added, as shown in Fig. 11, but the film did not tear because the concentration of erythritol was reduced.

The size of the crystals became smaller when coconut oil and lecithin were added to erythritol. This is likely due to the coconut oil interfering with the formation of crystals, and the addition of lecithin made the coconut oil and erythritol mix well, resulting in smaller crystals.

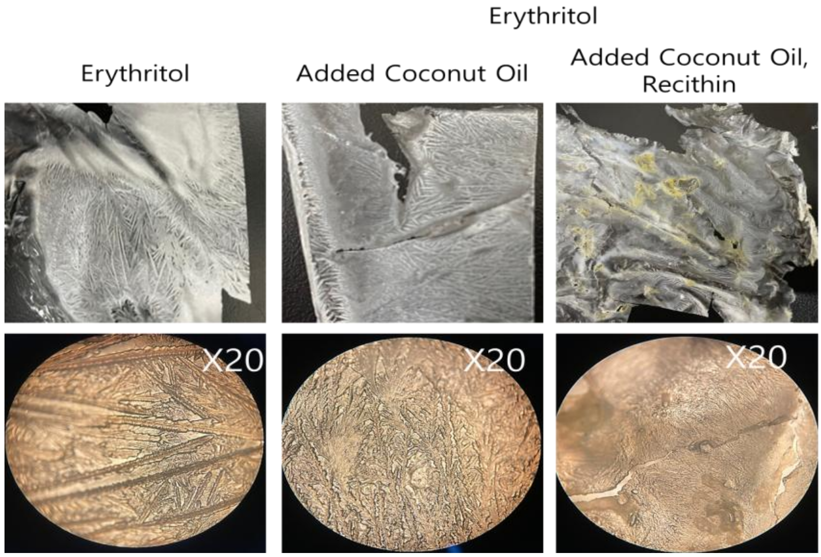

Fig. 11. Films were made by mixing erythritol with coconut oil and lecithin, and the crystals of erythritol in each film were viewed under a microscope.

Temperature change on the surface of the pigskin treated with each film

The process of applying the films made in Fig. 11 on pigskin was done twice, and the average temperature was compared. Unlike the reaction between film and water, the temperature gradually rose. The fastest increase was for the films that mixed the pullulan solution with erythritol, coconut oil, and lecithin. This was contrary to our expectation that the addition of lecithin would allow the coconut oil and erythritol solution to mix well and the temperature to decrease quickly. The lecithin seems to be more responsive to the water and temperature of the pork rind treatment when the coconut oil and erythritol are unevenly mixed than when they are mixed with the lecithin.

a) b)

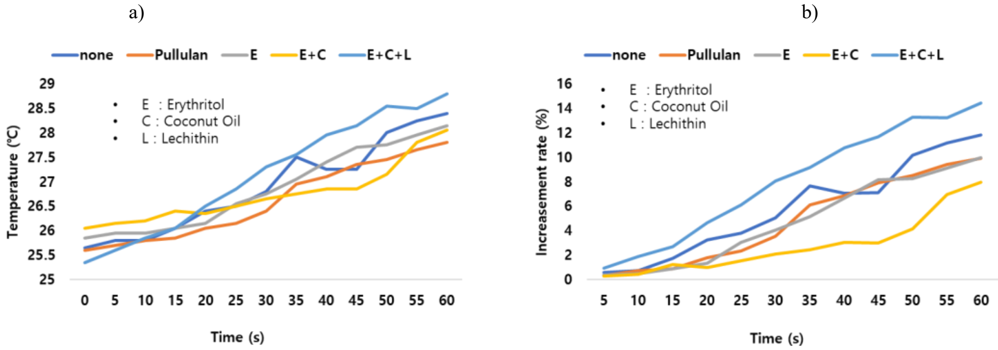

Fig. 12. a) Temperature change of pork skin after the removal of the film for 1 minute. b) Increase in temperature of the surface of pork skin

Changes in moisture, oiliness, and elasticity of dried pork skin at room temperature and 50°C

The moisture, oiliness, and elasticity of the film-treated pork skins were measured at 50°C. The results of Fig. 13a showed that the moisture of the pork skin without the film was the lowest at 22%, followed by the pullulan film at 66%. The remaining pork skins treated with the three films(E, E+C, E+C+L) containing 1% erythritol had moisture levels ranging from 97% to 99%. The amount of oil was similar between the control and film treatments, ranging from 19% to 23%, and the elasticity was higher for the remaining film treatments, ranging from 67 % to 71%, compared to 44% for the control. The reason for the high elasticity is that the moisture was retained well, and the pork rinds did not harden into a hard crust.

After 20 minutes in a desiccator, the moisture content was higher for the films compared to the control, as shown in Fig. 13 b, with the highest moisture content of 86% for the pullulan film, followed by 72%, 72%, and 70% for the films with E, E+C, and E+C+L respectively. The elasticity was highest for the pullulan film with high moisture content at 69% compared to 59% for the control, while E, E+C, and E+C+L were measured at 64%, 65%, and 64%. Based on the results above, the elasticity is proportionally measured when the moisture content is high, and it seems that the film prevents water evaporation to some extent, and the films containing erythritol, coconut oil, and lecithin, which mixes the two substances, all seem to retain water well.

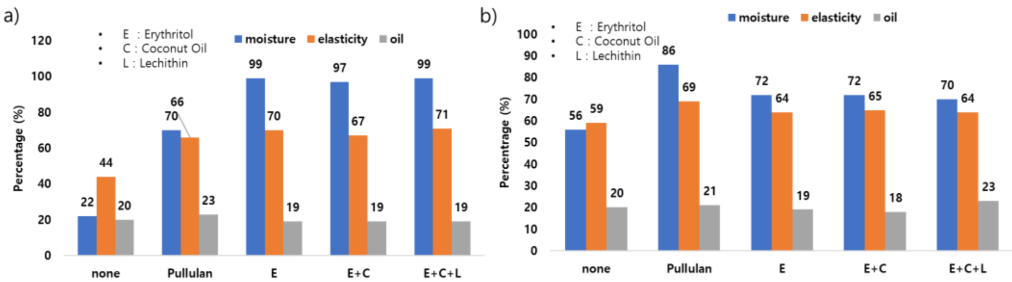

Fig. 13. Changes in moisture, oiliness, and elasticity of pork skin covered with a film made of erythritol, coconut oil, and lecithin, a) 20 minutes at room temperature b) 5 minutes in a dryer at 50 °C

Conclusions

To reduce the temperature of the dog's paw pads and increase moisturization, we decided to use the phase-changing substances erythritol and coconut oil in the form of a film. Erythritol produces an endothermic reaction when dissolved in water, and coconut oil reduces the temperature as it is dissolved by heat at about body temperature.

When 1,5, 10, and 15g of erythritol were dissolved in 50 ml of water, the temperature decreased as the amount of erythritol increased, with a final decrease of 8 °C at 15g of erythritol. The temperature of the coconut oil was checked when it dissolved from solid to liquid, and the temperature change was 2.63 °C, which did not change significantly. Coconut oil and erythritol were mixed in a solution of pullulan, which is highly soluble in water and can form a film. When erythritol was added to the pullulan solution to reach a concentration of 10%, the film didn't form well due to the crystallization of erythritol. When water was dropped on the film, the temperature decreased by about 6% compared to the control. When coconut oil was added to the pullulan solution to a concentration of 10%, the temperature changed by about 8% less than the control due to the low thermal conductivity of coconut oil. For this reason, when water was dropped on the film made with both erythritol and coconut oil, the temperature decrease was similar to the control.

To prevent the film from breaking, we decided to reduce the amount of erythritol and utilize coconut oil for its moisturizing effect rather than its ability to reduce temperature. Films were made using 1/100 and 3/100 of erythritol (g) / 1% pullulan solution (v). The inclusion of erythritol did not cause the films to break. When cutting each film into 5 ml of water, the temperature reduction of the 3% erythritol film was 3% lower than the pullulan-only control film. When the film was made with erythritol in a 3% pullulan solution, the temperature decreased by about 2% compared to the control, and the higher concentration of the pullulan solution slowed down the dissolution of the film. Films made from a 10:1 solution of coconut oil and sodium alginate with erythritol were also stale, but did not show a significant decrease in temperature. We also saw phenomena such as the film becoming sticky as the amount of erythritol increased. Therefore, the film was made with a ratio of 1:100 of erythritol (g) and pullulan solution (mL). In addition, coconut oil and lecithin were added at a ratio of 1/10 of erythritol, and the temperature change was observed when the film was applied to the surface of pork skin.

When the films were placed on pork rinds on top of a thermoelectric device maintained at about 40°C, the temperature did not decrease as it did in water. The rate of temperature increase was found to be 1.86% and 3.88% less for the films containing erythritol and coconut oil, respectively, compared to the control. The temperature of the film mixed with erythritol, coconut oil, and lecithin increased by 2.59% more than the control film. It is expected that the lecithin mixed with the coconut oil and erythritol will prevent the dissolution of each substance. It was expected that the erythritol in the mixture would prevent each substance from dissolving. When the pullulan film was applied to the pork skin, the moisture content increased by about 3 times compared to the pork skin sprayed with water alone, and in the erythritol film and the film mixed with erythritol, coconut oil, and lecithin, the moisture content increased by about 20% more than the pullulan film alone.

Based on the above results, the ideal film was 1% pullulan (100mL), erythritol (1g), and coconut oil (0.1mL). Unlike traditional moisturizers, the film can be applied to the soles of the feet after sprinkling water on them to reduce the temperature and moisturize them at the same time. However, when the film is dissolved and spread evenly on the paw pads, the sticky nature of erythritol can stick to the fur between the paw pads, so it is necessary to check the problem when used on actual dogs.

If this part is improved, the materials used in the film are all non-toxic, so it does not cause skin irritation, it is convenient to carry because it is in the form of a film, and it is close to zero waste because all the film melts away after use. In addition, it can be applied not only to dog paws but also to people who need to moisturize their skin

References

[1] Cohen, Philip R. *Comparative dermatology--pavement paws: frictional dermatosis in puppies analogous to pool toes,* **Dermatology Online Journal, 30, 4**, 2024.

[2] Miao, Huaibin, et al. *How Does Paw Pad of Canine Attenuate Ground Impacts: A Micromechanical Finite Element Study*, 2016, doi: 10.7287/PEERJ.PREPRINTS.2340V1.

[3] Kuznik, F.; David, D.; Johannes, K.; Roux, J.-J. *A review on phase change materials integrated in building walls,* **Renew. Sustain. Energy Rev.**, **15**, 2011, pp. 379–391.

[4] Grembecka, Małgorzata, *Sugar alcohols—their role in the modern world of sweeteners: a review,* **European Food Research and Technology**, **241**, 2015, pp. 1-14.

[5] Byun, Sang-Hee, and Cherl-Ho Lee. *Studies on physicochemical properties of erythritol, substitute sugar*, **Korean Journal of Food Science and Technology**, **29(6)**, 1997, pp. 1089-1093.

[6] Onishi-Sakamoto, Saki, et al. *Erythritol alters phosphotransferase gene expression and inhibits the in vitro growth of Staphylococcus coagulans isolated from canines with pyoderma,* **Frontiers in Veterinary Science, 10**, 2024, p. 1272595.

[7] Dean, I., F. Jackson, and R. J. Greenough. *Chronic (1-year) oral toxicity study of erythritol in dogs,* **Regulatory Toxicology and Pharmacology**, **24(2)**, 1996, pp. S254-S260.

[8] Gopalakrishna, A. G., et al.. *Coconut oil: chemistry, production and its applications-a review*, **Indian Coconut Journal**, 2010, pp. 15-27.

[9] Saleel, C. Ahamed, M. Abdul Mujeebu, and Salem Algarni, *Coconut oil as phase change material to maintain thermal comfort in passenger vehicles: An experimental analysis*, **Journal of Thermal Analysis and Calorimetry, 136**, 2019, pp. 629-636.

[10] Chew, Yik-Ling. *The beneficial properties of virgin coconut oil in management of atopic dermatitis,* **Pharmacognosy Reviews**, **13**(25), 2019, p. 24.

[11] Fiorell C, Jayanti PD, Dwinata IM, Sudimartini LM and Suartha IN. *Effectiveness of Coconut Oil Administration on Immunoglobulin E (IgE) Levels in Dogs with Atopic Dermatitis,* **International Journal of Veterinary Science and Medical Diagnosis**, **5(2)**, 2024.

[12] Wypij, Magdalena, et al. *Pullulan-based films impregnated with silver nanoparticles from the Fusarium culmorum strain JTW1 for potential applications in the food industry and medicine*, **Frontiers in Bioengineering and Biotechnology**, **11** 2023, p. 1241739.

[13] Rhim, Jong Whan. *Characteristics of pullulan-based edible films*, **Food Science and Biotechnology**, **12(2),** 2003, pp. 161-165.

[14] Adamy, S. T. *Moisture retention in a (in vitro) porcine skin substrate,* **International Journal of Cosmetic Science**, **25(6)**, 2003, pp. 285-293.

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