2022 年臺灣國際科學展覽會
優勝作品專輯

作品編號 **180014**

參展科別 **地球與環境科學**

作品名稱 **Bio-Circular-Green Superabsorber**

得獎獎項

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關鍵詞 **Biodegradable absorbent**

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Abstract

As the world has become concerned about the global waste crisis and global warming, there has been a surge of research within materials science to find materials that would replace plastic, such as bioplastics or biodegradable materials, in order to reduce environmental pollution. Plastics generates the microplastics that allowed them to become cross contamination enter the ocean through land, sea and river. Science research found over 220 species of marine animals ingested microplastic, half of them is considered relevant for commercial purpose and increasing the risk of human consumption as it can induce immune response, oxidative stress, cytotoxicity, alter membrane integrity and cause differential expression of genes.

Thailand is also experiencing such a challenge, as seen by the overabundance of plastic waste that might take centuries to decompose. For example, around 1,680 million personal hygiene products such as diapers, sanitary napkins, and tampons are used each year. This study highlights the use of naturally accessible absorbent fibers from malva nut (*Scaphium scaphigerum* (G. Don) Guib & Planch), which is widely available and biodegradable in nature and has a low carbon footprint. This study also aimed to develop natural absorbent pads using compostable spun, external composable layers, and biodegradable glue. A prototype sanitary napkin with biodegradable absorbent pads was developed and evaluated for absorption ability, absorption rate, pH, and biodegradability. The absorbent material absorbed up to 19 times its weight in 2 minutes and 33 times its weight in 2 hours, which is enough for an average of 80-150 mL of menstrual blood. The prototype napkin deteriorated within 99 days, based on naked eye observation. Some signs of degradation and microorganisms growing on the prototype were also observed from scanning electron microscopic images. According to the findings, natural absorbent pads made from malva nut have the potential to be converted into sanitary napkins. Furthermore, it is proposed that the components, which include superabsorbent renewable materials, spinning compostable layer, external compostable layer and biodegradable glue, may be used in a variety of goods, including adult diaper pants, incontinence pads, and laboratory bench mats.

Introduction

Worldwide cities are rapidly expanding, creating more waste destroying the environmental and social. Since 1990 the world's main cities population has grown in average 13% or around 220 million people. They created a 300 thousand tons per day. Ten years later, the people were driven by household economic so moving from the urban into the prime area main cities around the world has been increasing to 2,900 million people, 49% of total population around the world. With this numbers, around 3 million tons of waste per day has been creating continuously while the material resource become depletion critically and it expected to have more than doubled increasing environmental and social challenges in year 2025. [1] Mainly of several types of waste comes from plastic waste. They can be everywhere and everything in daily life as using of plastic is convenience such as straw, plastic water bottle even the sanitary napkins also made from plastic. The plastic made from petroleum-based that takes about 10 to 1000 years to decompose. While decomposing, the dimension size of petroleum-based plastic can be smaller into 1 nano meters to 5 millimeters which is so called microplastics. [2] Recently, the cross contamination from microplastic has become the global issue. The affect levels of biological organization high potential effect on human health. The microplastic can be of variable composition and it contains a wide range of additives such as pigments, ultraviolet stabilizers, water repellents, softeners – phthalates. The tiny size can be found in the food we eat and the water we drink. Even the synthetic fabric we wear can generate fibers – some studies have revelated textiles to be the major source of airborne microplastics. There are more than 100,000 microplastic particles surround by human each day through inhalation, ingestion and dermal absorption in the air, water, food and consumer products so that may be hazardous to human health. They might act as irritants, in much the same way asbestos fibers are known to inflame the lungs and cause cancer. Microplastics are also to act as vectors for microorganisms and toxic chemicals, thus posing further health risks. There is the potentiality for metabolic disturbance, neurotoxicity as well as carcinogenic effects.[3] The harmful effect of microplastics to the marine world. They are transferred and bioaccumulated in the food chain that cross to the humans. They can be remained in the guts of fish rather than moving into muscle tissue which is the part we eat it. The microplastics can degrade into nanoplastics floating in the surface of water, invisible to detect. They can be move into the cells, tissues and organs of human and marine life body. The affect is challenging to the human food chain their high-risk exposure to our human health.

Most people feel that disposing inorganic waste like plastic can be recycled or reused. However, non-biodegradable plastic recycling process creates hidden cost such as operation cost and requires technological advancement turning out recycling and reusing. The trash items that need to dispose by burning is usually a poor option. It can cause land, air and water pollution as they create CO_2 which is the major effect creating the Greenhouse Gas. The possibly high potential better way is trying to reduce and choosing the biodegradable plastic which is able to decompose by natural and convenience comply with the human in the main cities. The sanitary napkins in the market made from non-biodegradable plastic materials in each single layer. Harvard Business School reported one woman uses over 11,000 tampons over her lifetime. The report also found close to 20 billion wastes from menstruation are dumped into North America landfills every year. [4] The non-biodegradable waste in each single layers from sanitary napkins take more than 500 years to be decomposed completely. The previous research studied agarose gel (brown weed polymer) for renewable SAP (Super

Absorbent Polymer). The production was creating high cost as it required high temperature hot water 60 c degree at the preparation process. [5] [6] Soya protein was studied and found water uptake capacity could be 12 times. It even high potential water uptake to 36 to 40 times when molecular is improved. However, the material preparation process was complicated required freeze drying, make it dry and mix with plasticizers then go through the injection process that creating process cost and technological advancements. [7]

The Malva nut is the local plant and has long been used as traditional medicine in Thailand and Asia. [8] There are several commercial products selling in the markets to serve as drink and sweets which made from mucilaginous substance in order to reduce weight. This study considered renewable materials which was locally for sustainable ecosystem into local communities. The biodegradable sanitary napkins will be impact on the environment while compostable they return nutrients to the nature, the natural source of food for plants or even for Malva nut farms can make a full-circle of supply the substances as it is the key of renewable material to make the biodegradable sanitary napkins which is environment friendly.

Research Questions

Our study questions include if malva nut powder derived from malva nut mucilage can be used as an absorbent material and whether we can develop bio, circular, green superabsorbent pads containing malva nut mucilage powder.

Purpose

The aim of this study was to develop new absorbent materials from natural substances for replacing absorbent polymer using in sanitary napkins. It is able to decompose by natural as it is biodegradable materials. It can be different commercialize solutions in the market. Biodegradable sanitary napkin was designed by replacing non-biodegradable layers of common napkin with biodegradable polymer, and tested in accordance with the Thai Industrial Standards as well as its biodegradability. The prototype can be decomposed clearly, convenience for user and friendly with environment.

Materials

Natural absorbent materials selection:

Some natural materials were selected for testing in this study. They can swell or form gels by the combination of hydrophilic functional groups such as -OH, -COOH, NH_2 and -SOH through covalent bonds, hydrogen bond or interactions between other functional groups in a chain. This makes the structures have many porous that can absorb water and bio-based solutions to form gel. However, the absorption rate isn't stable.

Malva nut
The mucilage of the malva nut inflates and swells to form a brown gel that is edible. It is known as a weight-loss diet, and it also helps in excretion. The absorbent ability of the malva nut is up to 40-45 milliliters without heat exerted. [9]

Sodium carboxymethyl cellulose
Sodium carboxymethyl cellulose, a derivative of cellulose, is a gelling agent. It can dissolve in water at any temperature. In fact, it can be synthesized from the cell wall's cellulose. It is stable at pH 4-10 and has the highest viscosity at pH 7-9. [10]

Sodium alginate
It is a carbohydrate produced by algal cell membrane. It is grouped in viscous glue, which is widely used in food, textile, pharmaceutical industrials. It can be used as a gelling agent [11] or a supporting agent in tissue engineering or bone cell transplants. [12]

Hydroxypropyl methylcellulose
It is a gelling agent that some parts of the cellulose chain in the hydroxyl group are replaced with methyl, so it decreases hydrogen bonding among the cellulose chain, which makes the substance capable to absorb water. In pharmaceutical sciences, it is used to increase viscosity, which is in the form of white powder. When it dissolves in water, it will become a clear gel. [13]

Hairy basil seed
Hairy basil or *Ocimum africanum* Lour is a herbaceous plant in the genus Basil and Thyme. Its seed, when leaving in water, can form a white gel covering the seed called Ocimum canum. It can absorb water up to 45 grams per one gram. [14]

Pregelatinized starch
It is a gelling agent, which made of modified starch. The process is using heat to modify starch, then drying it by using a single drum dryer and spray drier. The process can break the hydrogen bond and makes the substance capable to absorb water at low temperature. It is suitable for food products and other products that want viscosity with using heat. [15]

Biodegradable composable layers:

First layer: the muslin sheet was selected as it is normally used with infants who are more likely to be allergic than adults.
Second layer: the second layer is used for increasing the speed of absorption, so it needs to be a light material that can absorb water easily. We decide to use cotton pads because it is completely made by cotton and be able to absorb water speedily.
Third layer: the third layer is our developed absorbent layer, which contains powders from malva nut mucilage. However, there is needed to have a plate that hold the powder, so we choose a bioplastic called polybutylene succinate (PBS) as the plate's material. The bioplastic is a combination of succinic acid and 1,4 butene dion. It is made from plants, for example, sugar cane and cassava, and has been used as packaging, food wrapping, and textile industrials. For its degradability, it can decompose within 189 days in the environment that the temperature is lower than 55 degrees Celsius and humidity at 50-55%. [16]

Fourth layer: the fourth layer is used for protecting the leak of liquid from sanitary napkin. Polylactic acid-based blend, which is the combination of bioplastics, such as polylactic acid (PLA), polybutylene adipate terephthalate (PBAT), PBS, and other bioplastics, was used. The combination makes the material to be impregnable, resistant to form, and reducing tensile strength. PLA is made from corn, cassava, or sugar cane. It is capable to form in typical thermoplastic processes, for example, extrusion and injection process. [17] [18]

Methodology

1. Market survey by creating the questionnaire to determine customers using napkins and market segmentation classified from age, education, pricing and usage.
2. Water uptake capacity using tea-bag method

   Controlled variables (Blank) are filter papers covered by tea bag, temperature, relative humidity, chemicals' mass, type of the filter papers and tea bags, and the pH values of solutions.

   Independent variables are the 6 substances for experimentation, including malva nut's mucilage, basil seeds, sodium alginate, pregelatinized starch, carboxymethyl cellulose, and hydroxypropyl methylcellulose.

   Dependent variables are each substance's water uptake capacity after the lapses of 2, 5, 10, 15, 30, 45, 60, and 120 minutes.

   Water uptake capacity [19]

   $$\text{Water uptake capacity} = \frac{(\text{substance's weight after absorption at each lapse} - \text{initial weight of substance})}{initial\ weight\ of\ substance}$$

3. Increasing the absorption ability of the malva nut mucilage absorbent

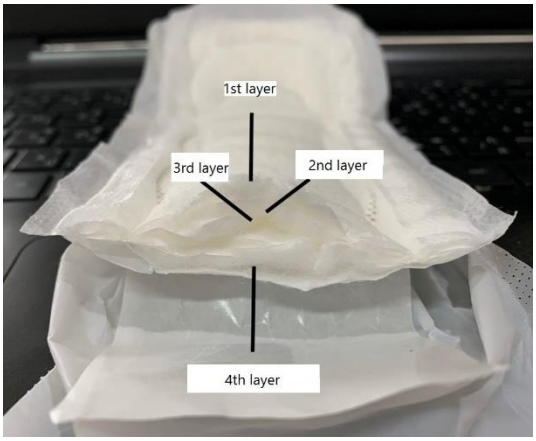
   When each single material has been tested, the highest absorption ability was malva nut mucilage.

   Enhance absorption ability on mucilage malva nut, we conducted the specimen testing into 2 methods.

   3.1. Oven baking in 50 degrees Celsius

   3.2. Freeze drying method

4. **The prototype of sanitary napkin using the substance with the best water uptake capacity and composable materials.** There are four layers as following ;
   4.1 100% cotton cloth baby diaper. The permeable surface's (top sheet) material is sparse or porous to allow water through.
   4.2 Cotton wool or pad, which is the absorption speed auxiliary that has softness and hygiene.
   4.3 The natural absorbent material has high water uptake capacity and is a hydrogel. We selected the mucilage malva nut as it has the best absorption capacity. The key material was combined with the polybutylene succinate which is the bio-plastic using Rotation Jet Spinning.
   4.4 The impermeable backing is a thin film made of polylactic acid-based blend.



Packaging

Research reported that different types of bio plastic have different waterproof abilities. The selected material was the one which high vapor transmission rate (WVTR) and oxygen transmission rate (ORT) [20]

Bio-based adhesive

As the results in the market survey, we found that they have an issue with the adhesive strip. The adhesive used for pad attachment is visible for women as they placed the pad in their underwear. The adhesive plays a significant role in ensuring the pad stays in place during use. If any sticky residue is noticed after the pad is removed, or the adhesive is too strong to remove, the user may become dissatisfied with the quality of a product. The existing adhesive used in sanitary napkins in the market is non-biodegradable. The research from the *International Journal of Adhesion and Adhesive* studied the replacement of methyl methacrylate by sustainable bio-based isobornyl methacrylate in latex pressure-sensitive adhesive as so-called IBOMA can be used to replace petroleum-based methyl methacrylate (MMA) as it is a hard monomer in the application of acrylic latex pressure-sensitive adhesive (PSA). The results of the investigation have shown the positive results with high potential to be the solution for our target group requirements; friendly environment, placing, stay in place, and removing easily from the garment. [21]

5. The desired quality assessment test based on the Thai Industrial Standards (TISI 295-2560) for sanitary napkin [22]

   a. Water uptake capacity testing
   b. Water uptake speed testing
   c. pH testing



6. Biodegradation testing of the sanitary napkin model

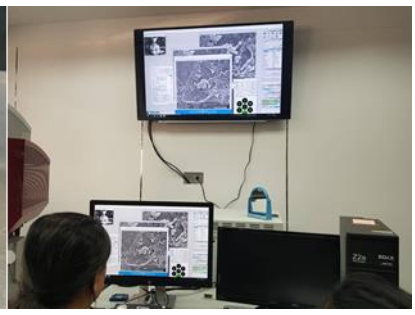
Two methods were applied to see the composable by naked eyes and Scanning Electron Microscopy (SEM)

Naked eyes

The specimens were prepared by placing them into the wood frame. The frames with specimen were put into the soil, which mixed with fertilizer at a ratio of 5:1. Water pouring was done every week and the changes were observed every 20 days.


Scanning Electron Microscopy (SEM)

After ten days, the frames with specimen were removed from the soil for SEM observation.

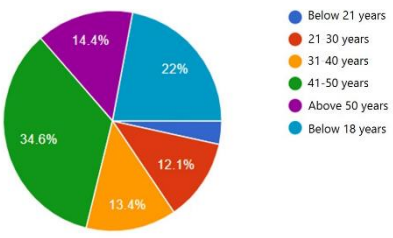



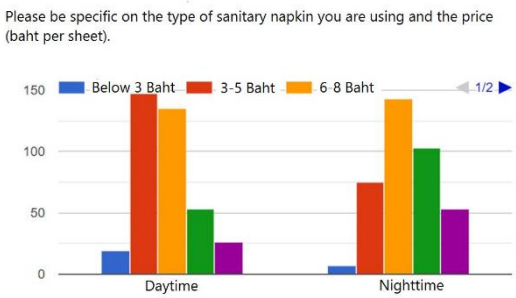
7. <u>Maximum water uptake capacity test for the model sanitary napkin</u>
    - independent variable refers to the number of the third layer (absorbent layer) used in the prototype.
    - The dependent variable refers to maximum water uptake capacity of the prototype with the different number of absorbent layers.
    - The controlled variable refers to the mass and size of the other layers in the prototype.

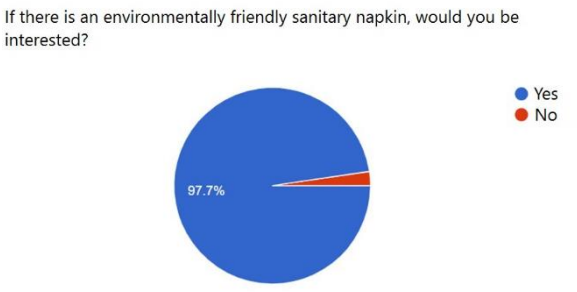
Results and Interpretation of results

1. Market survey customer requirements

In the research regarding to the questionnaire, we distribute to the women age under 21 to 50 years old asked questions on their behavior, salary, expense on napkins, where to buy, on their attitudes toward the napkin price acceptance. We found in the focus group age between 41 – 50 years old earn salary higher than USD 1,500 a month while the age under 21 years old this group earn less than USD 285 per month. The study identified focus group more than 50% of them will purchase the napkins which has more special qualifications added in the sanitary napkins new formulation such as feel cool and fresh in order to relieve stuffy discomfort and no worries on odor. The study identified more than 71% of focus group purchase sanitary napkins from supermarket in department store while 26.5% purchase from convenience stores. The prices are in range of USD 0.085 to 0.14 per piece for day type and USD 0.17 to 0.23 for night type. More than 50% interesting in love earth safe earth. This study identified the reason of driving on spending higher price for environmental saving they care of.







2. Selection of materials

To find the best material which has absorption ability by Tea bag method. The study found mucilage malva nut was the best material. They could absorb more than 33 milliliters per 1 gram malva nut within 2 hours. They also absorb 19 milliliters per 1 gram malva nut within 2 minutes speed.

3. Water uptake testing using teabag method

Recorded testing environment: temperature 27.5 degree Celsius, 71% humidity.

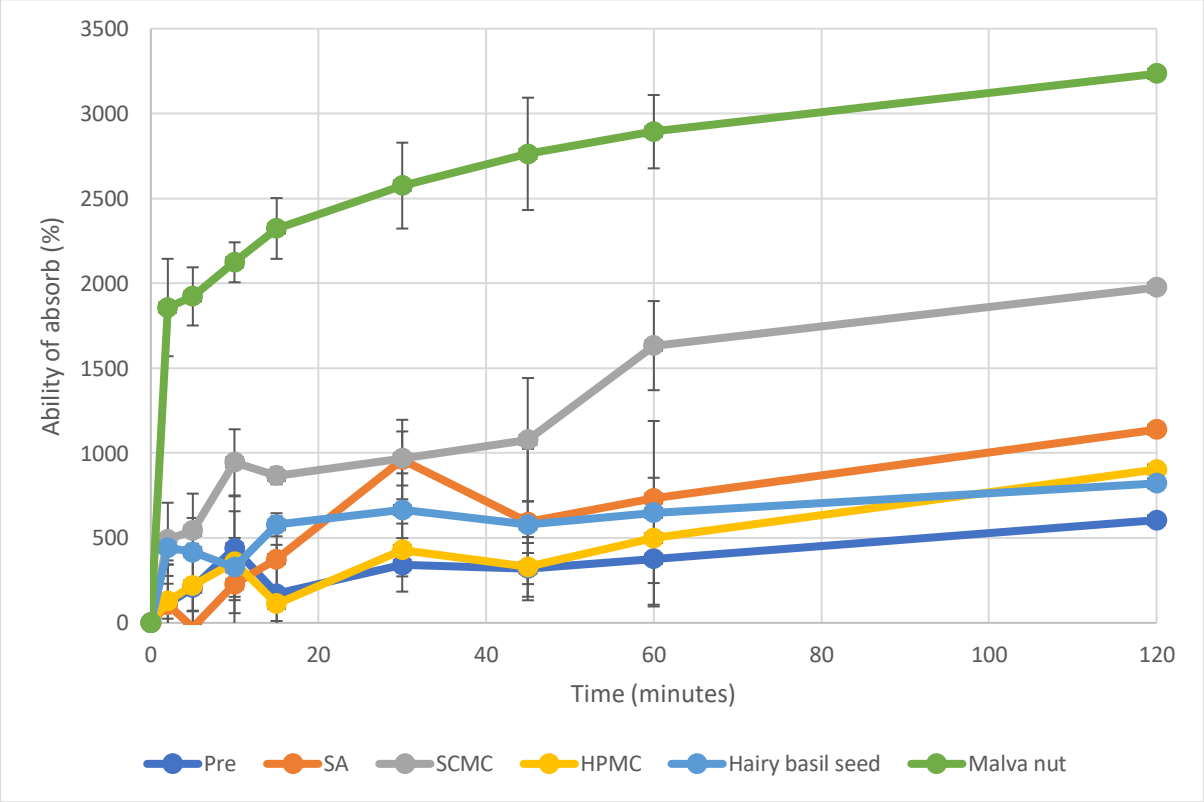


Figure 1: Water uptake of various substances

From Figure 1, It is seen that malva nut mucilage powder had the highest water uptake, followed by carboxymethyl cellulose, sodium alginate, hydroxypropyl methylcellulose, hairy

basil seed, and pregelatinized starch, respectively. Malva nut can absorb water of 3264% or 33 times of its own weight. Moreover, malva nut showed the fastest water uptake (about 19 times of its own weight within 2 minutes).

When two drying methods, oven drying at 50 degrees Celsius and freeze drying, were compared, the study found that the malva nut powders prepared by freeze drying approach increased absorption capability more than those prepared by oven drying method (Table 1).

Table 1: Absorption capability of malva nut mucilage powders at different times

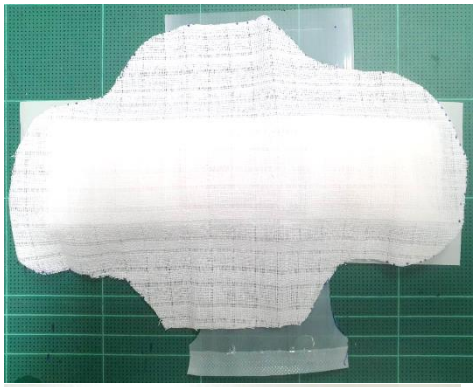
	Malva nut's absorption capability within 2 minutes	Malva nut's absorption capacity within 2 hours
Oven dry (50 degree Celsius)	13 times of its weight	24 times of its weight
Freeze dry	19 times of its weight	33 times of its weight

4. Prototyping the sanitary napkin

The developed biodegradable sanitary napkin prototype composed of 4 layers as shown below.

Table 2: comparison of components of the model with commercial sanitary napkin

Napkin's components	Biodegradable napkin	Commercial napkin
First layer	Muslin sheet	Non-woven PP (polypropylene)
Second layer	Cotton wool	Cotton wool + polyacrylic acid or sodium polyacrylate
Third layer	PBS + malva nut's mucilage powder	
Fourth layer	polylactic acid-based blend	PE (polyethylene)




5. Water uptake capacity testing of the model sanitary napkin

Table 3: comparison of the water uptake capacity

Number of absorbent layers (layer 3: PBS + malva nut mucilage powder)	Malva nut mucilage powder (grams)	Maximum water uptake capacity (milliliters)
2 layers	1.5	$\leq$ 50
3 layers	2.25	$\leq$ 60
4 layers	3	$\leq$ 60

With 4 layers, the sanitary napkin model could absorb up to 60 milliliters of water while maintaining the concentration of malva nut gel at 4.8% w/w, which is the concentration that gives integrity to the gel in addition to high modulus.

6. Quality assessment of the model sanitary napkin based on the Thai industrial standards (TISI 295-2560)
    a. The water uptake capacity testing showed that the model was able to absorb over 10 milliliters, qualifying it as highly absorbent.
    b. The water uptake speed testing showed that the model was able to absorb water in 3.23 seconds under the set limit of 15 seconds.
    c. The testing of pH value read 5.76 when tested in distilled water with pH of 6.17; the standard pH value is between 5.0-8.5.

From the results, the prototype met the standards, both water uptake and pH testing.

7. Biodegradation testing of sanitary napkin model

Table 4: comparison of the sanitary napkin model's layers after biodegradation testing

layer 1	pre-burial	40-day burial	75-day burial
Muslin sheet			No record, as the layer has completely decomposed after 40 days.
After 40 days, cotton decomposed completely.			

layer 2	pre-burial	40-day burial	75-day burial
cotton wool			No record, as the layer has completely decomposed after 40 days.
After 40 days, the second layer made of cotton wool decomposed completely.			

layer 3	pre-burial	40-day burial	75-day burial
layer of PBS + malva nut mucilage			
After 75 days, the 3rd layer made of PBS + malva nut's mucilage decomposed completely.			

Layer 4	pre-burial	40-day burial	75-day burial	99-day burial
PLA-based blend				
After 99 days, the fourth layer decomposed completely.				

By naked eyes

In this study, it is observed that all layers of the prototype sanitary napkin made from bio-based materials were composable within 100 days, which is in the faster than a previous report that found polybutylene succinate and a polylactic acid-based blend to be composable within 3-6 months [23].

Scanning Electron Microscopy (SEM)

Microbes such as bacteria and fungi were detected in the scanning electron microscopic images (Figure 2); they were living and digesting the prototype's layer. According to the findings, the prototype is biodegradable.

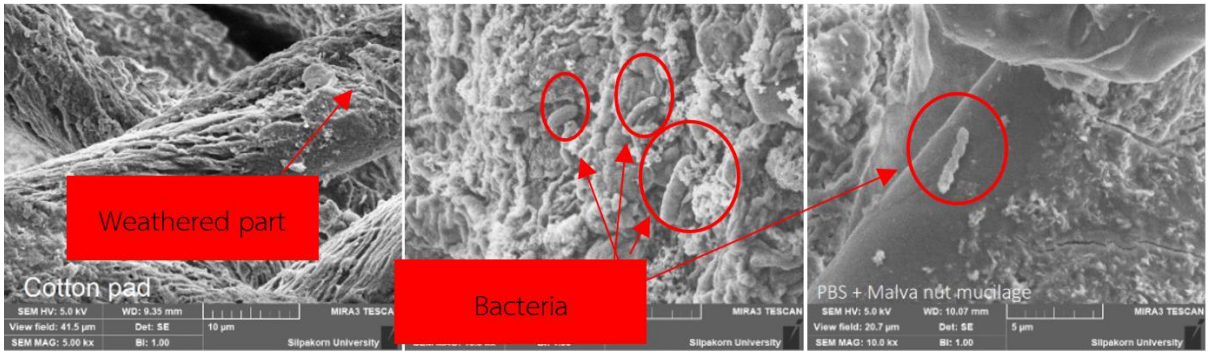


Figure 2: Scanning electron microscopic images of some layers of the prototype after biodegradation testing

Conclusions

The study discovered the prototype sanitary napkin made from composable material, malva nut mucilage powder, which could absorb up to 33 times of its initial weight. It may replace the synthetic absorbent polymer in commercial sanitary napkin. Moreover, the developed prototype of natural absorbent pads using compostable spun, external layers, and biodegradable glue passed the Thai Industrial Standards (TISI) for sanitary napkin. Also, it was biodegradable, non-toxic, and had the maximum water uptake capacity of 60 milliliters, which is sufficient for the average 80-150 milliliters of menstrual blood per cycle, given that a regular napkin absorbs about 30-40 milliliters on average.

Challenges and suggestions from the experiment

- The knowledge from this study could be applied to other solutions such as diapers for baby and elder, incontinence pads, and laboratory bench mats.

- The protoype has been protected from water, air and microbes by the two layers of biodegradable plastic sheets, which help to extend the shelf-life of the products for about 2 years. However, the shelf-life of the developed prototype should be tested in the future before commercialization.
- Moreover, the sterilization of the pads should be considered for the product development. We suggested that the irradiation by gamma ray with the intensity of 25 kGy could be used to eliminate the microbes [24] from natural sources and during the production processes.
- The allergy test should also be performed although our prototypes were made from 100% natural materials. It is reported that the babies have a higher allergy opportunity to muslin cotton (generally used in baby cloth diapers) than adults [25].

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【評語】180014

The plastic use is a very serious problem recently. Biodegradable materials or bioplastics development is an important issue to prevent the global waste crisis. This study aims to develop a natural absorbent pads using biodegradable materials. The natural absorbent pads made from malva nut is biodegradable and super-adsorbent. However the water uptake testing should be described with more detail.