JUSAMI
Jurnal Sains Materi Indonesia

ORIGINAL ARTICLE

Synthesis and Characterization of Biocompatible Facial Sheet Masks Utilizing Ginger Cellulose and Jicama Starch

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ABSTRACT – Sheet masks are one of the most widely used beauty products to improve skin health. The increase in sheet mask usage leads to an increase in its waste, while some of the sheet masks contain synthetic fibers that are not biodegradable in the environment. Many researchers have been interested in innovating sheet masks by using natural polymer materials. Starch and cellulose were chosen because they are potentially environmentally friendly and biocompatible products. The solution casting method is used to produce sheet masks. Ginger cellulose and jicama starch were mixed, and the mass ratios of cellulose and starch are 100:0, 100:20, 100:40, 100:60, and 100:80. The addition of starch to cellulose tends to decrease the tensile strength and increase the percent elongation of the sample. The sample with a 100:0 ratio had the highest tensile strength at 34.75 MPa, while the highest percent elongation was achieved by the sample with a 100:40 ratio, measuring 4.80%. The absorption index of the sample to serum decreased with increasing starch composition. Samples with a mass ratio of cellulose to starch of 100:0, 100:20, and 100:40 exhibited better biodegradability than commercial sheet masks. Most of the samples undergo 100% biodegradation after 12 days of the biodegradation test. This research aims to develop a sheet mask made from ginger cellulose and jicama starch, which has flexible properties that allow it to conform to the shape of the face while also effectively absorbing serum or essence. This research can be used as an alternative for choosing sheet mask materials as a way to reduce plastic waste.

INTRODUCTION

Sheet masks are among the most commonly used beauty products to promote skin health. They function as agents to deliver bioactive molecules, such as serum and essence, into the skin, thereby improving the skin condition. Using facial masks can result in a smoother skin layer, increased hydration, and reduced evaporation, making the skin moist and healthy [1]. Sheet masks have gained significant popularity, particularly in Asia [2], due to their effectiveness and ease of application [3]. Sheet masks can be made from various materials, including cotton, hydrogel, bacterial cellulose, and others. Conventional sheet masks are primarily made from synthetic fibers or nonwoven fabrics [4], [5]. Consumer are becoming more concerned with improving their facial health care and beauty, leading to an increase in the popularity of facial sheet masks [5]. The increase in sheet mask usage leads to an increase in its waste. Plastic waste generated from skincare products, particularly sheet masks, requires critical consideration due to its rapidly increasing prevalence in the beauty industry and significant environmental implications. Synthetic sheet mask materials do not decompose readily, leading to a buildup in landfills and contributing to microplastic pollution upon disposal. Innovation in materials for biodegradable sheet masks is needed to address this issue.

Biopolymers can be selected as raw materials for facial sheet masks due to their excellent biocompatibility and biodegradability properties. Starch and cellulose are the most used biopolymers in cosmetics and medicine. Research indicates that cellulose exhibits good biocompatibility with human tissues, enhancing its acceptance in cosmetic formulations designed for direct application on the skin [6]. De Almeida et al. reported that bacterial nanocellulose has been used as the basic material for making sheet facial masks. Based on research, taking advantage of its greater mechanical performance and elasticity makes it particularly resistant to handling, simple to use, and able to adhere to skin perfectly, enhancing the penetration of active ingredients into the skin. [7].

Starch is one of the most abundant biopolymers, consisting of amylose and amylopectin, and has diverse applications due to its biocompatibility and ease of modification, which improves its functionality in packaging, biomedical fields, and

cosmetics [8], [9]. Recent studies highlight developments in using starch nanoparticles, which result in desirable properties that enhance moisturizing properties in cosmetic masks [10].

Cellulose is also a biopolymer that can be used as a material for facial sheet masks and is easily found in various types of plants. Cellulose has water absorption abilities and good mechanical properties, making it suitable as a sheet mask base material. In general, starch has lower mechanical properties compared to cellulose. The addition of starch to cellulose is expected to improve formability so that the resulting facial masks can resemble commercial products. As reported by Coltelli, poly(hydroxyalkanoates) (PHA)/starch prepared with rice husk composites is used to create the flexible and hydrophilic material needed for beauty masks as a matrix to fit the facial curve [11].

Cellulose and starch have good biodegradability and biocompatibility. Research conducted by González-Pérez et al. showed that starch films and starch-cellulose composite undergo biodegradation, with a value above 80% disintegration degree after 15 days [12]. Starch films derived from various botanical sources also undergo a mass loss exceeding 90% after 30 days, with cassava starch showing a high degradation rate and potato starch presenting the least degradation among the studied variants [13]. Faiza et al. reported that bioplastic films from starch and cellulose experience biodegradation in 7 days, with the highest value of mass loss being 63.181% for biofilm with 4% cellulose. Thus, cellulose and starch are suitable as alternative materials for sheet masks, thereby reducing plastic waste in cosmetics.

Various sources are used to obtain biopolymers as an alternative material for sheet masks, including jicama and ginger. Research has shown that jicama can be used to create peel-off gel face masks, while ginger is also suitable for this purpose, and its extract can serve as an ingredient in balms [14], [15]. In this research, starch was extracted from jicama, and cellulose was isolated from ginger. Among various sources of starch, jicama (Pachyrhizus erosus) contains approximately 4.4 to 10.6 g of starch per 100 g, making it a notable candidate for industrial applications [16], [17]. Jicama is often used in cosmetic formulations due to its beneficial properties, which contain ascorbic acid (vitamin C). Vitamin C is recognized for its role in enhancing skin health by inhibiting melanin production, preventing hyperpigmentation, and potentially leading to more radiant skin [18]. For cellulose sources, Ginger (Zingiber officinale Rosc.) contains approximately 62% to 88% cellulose, depending on the chemical treatment used for its isolation [19]. In addition to consumption, ginger can be used in the world of cosmetics and health due to its bioactive compounds, such as gingerols and shogaols, which function as antioxidants and anti-inflammatories. Based on Statistics Indonesia (Badan Pusat Statistik, BPS), the production of ginger in Indonesia reached 198.87 kilotons [20]. Due to its significant annual production, ginger has great potential as a natural source of antioxidants. Additionally, its waste can be processed to extract cellulose fiber.

In this research, a bio-composite with a matrix of jicama starch and reinforcement of ginger cellulose fiber is used as the basic material for sheet face masks. This bio-composite was made by isolating the starch and cellulose fiber, then forming it into a composite using the solution casting method. Variations of the composition of the samples are used to perceive the best design with excellent properties. Bio-composites for sheet masks are expected to exhibit properties similar to commercial sheet masks. Characterization methods such as tensile tests were carried out to obtain the tensile strength properties of sheet masks, absorption ability tests to determine the absorption ability of face mask sheets towards active ingredients such as serum and essence, and a biodegradation test was conducted to ensure that the resulting products do not contribute to plastic waste that is difficult to decompose. This research aims to develop a sheet mask made from cellulose and starch, which has flexible properties that allow it to conform to the shape of the face while also effectively absorbing serum or essence. Additionally, this product has the potential to reduce the plastic waste produced by conventional sheet masks.

EXPERIMENTAL METHOD

Materials and Instruments

Ginger was obtained from Ponorogo, Indonesia. Ginger fiber was obtained by blending the ginger using a Digimatic Blender. Jicama was obtained from Purworejo, Indonesia. The jicama extract and waste were separated using the Oxone Juicer. The alkalization process of ginger cellulose was performed using a CORNING PC-420D Stirrer. Gelatinization of starch and mixing cellulose and starch were conducted using Thermo Scientific Cimarec Stirring Hotplates.

Visual characterization of the sheet mask was conducted using a Nikon Stereo Microscope. A tensile test of the sheet mask specimen was carried out using an INSTRON Universal Testing Machine. The absorption capability of the sheet mask was evaluated using two active ingredients, hyaluronic acid and tea leaf extract. The tensile strength, absorption capability, and biodegradable test of the samples were compared to a commercial sheet mask, which has a nonwoven structure.

Method and Procedure

Isolation of Cellulose and Starch

Ginger fiber was obtained by blending the ginger, and the waste was dried for 24 hours at room temperature. Ginger fiber was isolated through an alkalization process using 6% w/v sodium hydroxide (NaOH) to remove lignin and impurities from the fibers. The concentration of NaOH was chosen based on previous research, which showed that isolation using 6% w/v NaOH results in a cellulose film with excellent absorption capability and biodegradation properties. The isolation process of ginger cellulose using 6% w/v/ NaOH resulted in above 40% cellulose content [21]. The jicama, which was 4 months old,

was processed by putting it in a juicer to separate the dregs and the jicama extract. It was then left for 12 hours until there was a separation between starch and water. An amylum test was then carried out by adding two drops of Lugol reagent to 0.5 g to determine the change in starch color.

Production of sheet mask: A 1% w/v cellulose solution was prepared by mixing 3.1 g of ginger cellulose and 310 ml of water at 50 °C. The cellulose was blended until it was evenly dispersed in the water. Before adding the starch solution to the cellulose solution, the blended ginger cellulose is filtered using a sieve. If the ginger cellulose is still clumpy, it is blended again until smooth and evenly dispersed.

In a separate container, starch was mixed with hot water at 80 °C, and glycerol 10% as a plasticizer was added to gelatinize it. The starch solution was added to the cellulose solution, and the mixture was stirred for 2 hours at a constant temperature of 80 °C. The cellulose-starch combination was poured into an 18.5 × 23 cm mould and allowed to dry at room temperature. The amount of starch added to the cellulose solution varied, resulting in sample sheets with different mass ratios of cellulose and starch, as shown in Table 1. Commercial sheet masks marked with sample code X were used for comparison.

Table 1. The mass ratio of cellulose and starch

No	Sample Code	A mass comparison of cellulose and starch	Cellulose Composition (% w/w)	Starch Composition (% w/w)	Information
1.	P0	100:0	100	0	Experiment
2.	P20	100:20	83.33	16.67	Experiment
3.	P40	100:40	71.43	28.57	Experiment
4.	P60	100:60	62.50	37.50	Experiment
5.	P80	100:80	55.56	44.44	Experiment
6.	X	-	-	-	Commercial

Visual Observation

The sheet face mask sample was prepared and observed under a microscope. Characterization using a stereo microscope was performed to determine the morphology of the sheet mask surface.

Mechanical test: Tensile testing was carried out according to ASTM D882 to determine the ultimate tensile strength and percent elongation of a sheet mask. The results of the tensile testing of sheet masks will be compared to the commercial products. Each sheet face mask sample was tested three times; in comparison, the commercial sheet face masks were tested four times in two different directions, longitudinal and transverse directions. In tensile testing of commercial sheet face masks, the longitudinal direction is axis 1, and the transverse direction is axis 2, as shown in Figure 1. The tensile strength and percent elongation of the sample were determined using Equation (1) and Equation (2) [22], where P is load (N), A is cross-section area (mm^2), L_0 is the initial gage length of the specimen (mm), and L_1 is the final gage length (mm).

$$\sigma = \frac{P}{A} \tag{1}$$

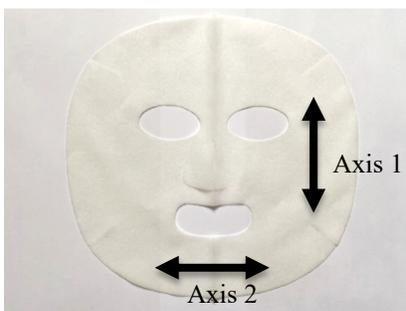$$\%EL = \frac{L_1 - L_0}{L_0} x100\% \tag{2}$$

Figure 1. Commercial sheet mask

Absorption Capability Test of The Sheet Mask

The absorption ability test was carried out by preparing a sheet mask sample and soaking it in the active ingredients, hyaluronic acid and tea leaves extract, for 10 minutes. The sample of the sheet mask was then removed and gently wiped using a tissue until no active ingredients were dripping. The absorption index of the sample was determined based on Equation (3) [23], where W_0 was the initial weight of the specimen, and W_1 was the weight of the specimen after immersion.

$$Absorption\ index\ (\%) = \frac{W_1 - W_0}{W_0} x100\%$$
(3)

Biodegradation Test

The biodegradation test of sheet face mask samples was carried out in soil with a pH of 4–7 and humidity of $60 \pm 5\%$ [24]. Before testing, the soil pH was tested by preparing 1 g of soil and 20 mL of water, and then measuring it using a pH indicator paper. A sample of sheet masks was soaked in the active ingredient for 10 minutes, then left for 15 minutes before being placed into the soil. Then, the sheet face mask sample was placed in a container and placed indoors, but still exposed to sunlight. Specimens of sheet masks were taken from the container every three days for 12 days and cleaned of dirt. The area was then measured using the ImageJ application. The percentage change in specimen area after 12 days can be calculated using Equation (4), where $\%\Delta A$ represents the percentage change in area, A_0 is the initial area of the specimen (mm²), and A_1 is the final area of the specimen (mm²).

$$\%\Delta A = \frac{A_0 - A_1}{A_0} x100\%$$
(4)

RESULT AND DISCUSSION

Visual Observation

Jicama starch and ginger cellulose were isolated before making sheet masks. The isolation of ginger cellulose involved an alkalization process. The alkalization process consists of the application of sodium hydroxide (NaOH) to remove non-cellulosic components, such as hemicellulose and lignin, resulting in a higher cellulose content that enhances mechanical properties [25]. The ginger pulp obtained has a brown color, while the jicama starch obtained is white and odorless [26]. An iodine (starch) test was conducted to confirm the presence of starch in the precipitate. The test showed that the precipitate obtained from the jicama extract turned black upon adding Lugol's reagent, indicating the presence of starch. The resulting sheet face mask sample is brown primarily, as depicted in Figure 2. Most commercial sheet masks are white. It is different from the achieved sample in this research because no bleaching process is conducted after alkalization. The bleaching process will decrease the lignin composition [27], resulting in lighter colors. The brown dots in Figure 2 represent ginger that the blender was unable to crush. Ginger fragments can also be observed under a stereo microscope.
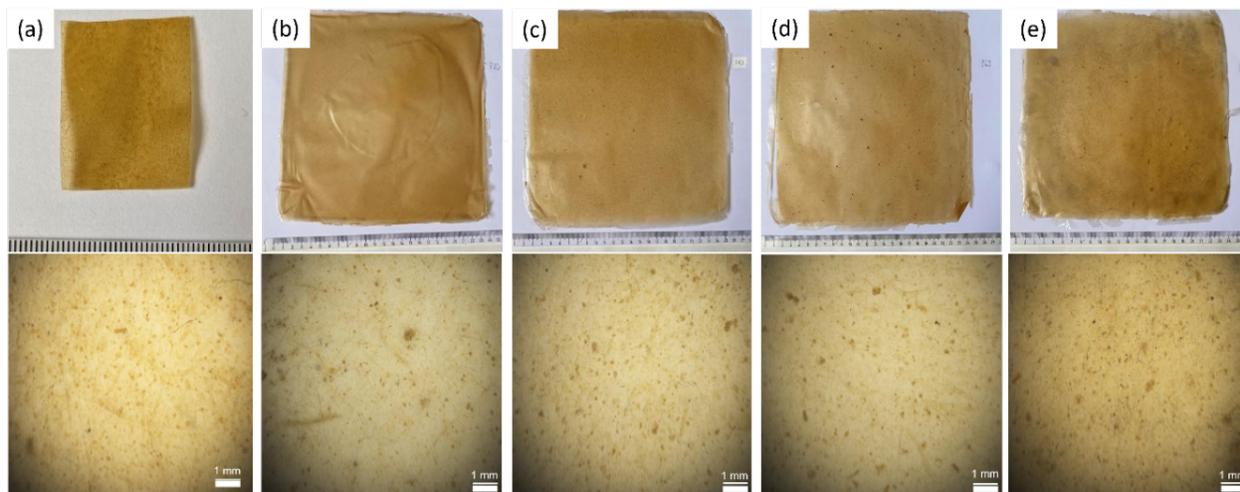

Figure 2. Sheet masks sample and microscope stereo result: (a) P0, (b) P20, (c) P40, (d) P60, and (e) P80

Mechanical Testing

The tensile testing was performed to evaluate the tensile strength and percent elongation of sheet masks. Based on the tensile test results depicted in Figure 3(a), sample P0 has the highest tensile strength, with the value of 34.75 MPa. Sample P0 only consisted of ginger cellulose, and cellulose is known to have better mechanical properties. Research conducted by Xia et al. showed that cellulose-based films could reach 23.16 MPa in tensile strength [28]. Other research showed that the tensile strength of starting cellulose film before the addition of phenol formaldehyde resin is about 40 MPa [29]. The addition of starch to cellulose-based films improves their flexibility, allowing the produced sheet mask to conform to the face's shape. Starch has lower tensile strength compared to cellulose. Research showed that starch-based bioplastics that use glycerol as a plasticizer and contain no filler materials exhibit tensile strength values ranging from 0.22 to 18.49 MPa across different starch varieties [30], lower than cellulose-based films. The tensile test results in this study were similar to those reported by Antosik et al. The research showed that increasing the starch concentration resulted in a lower tensile strength and a higher percent elongation [31]. The experimental test results show an increase in ultimate tensile strength on sample P40 with a value of 24.78 MPa, followed by a decrease in tensile strength. Research conducted by Islam et al. also yields similar results, with different cellulose-to-starch ratios ranging from 10:0 to 1:9, and the highest tensile strength value was obtained with a 6:4 ratio of cellulose and starch [32]. The ultimate tensile strength of sheet mask samples is higher than the commercial samples. The commercial sheet face mask chosen for comparison has a nonwoven structure formed by stacking continuous cellulose fibers, which results in a lower tensile strength. Commercial sheet masks contain fibers arranged less tightly, while the produced sheet mask sample contains short fibers arranged tightly and randomly, making the fibers entangled, as seen in Figure 4.
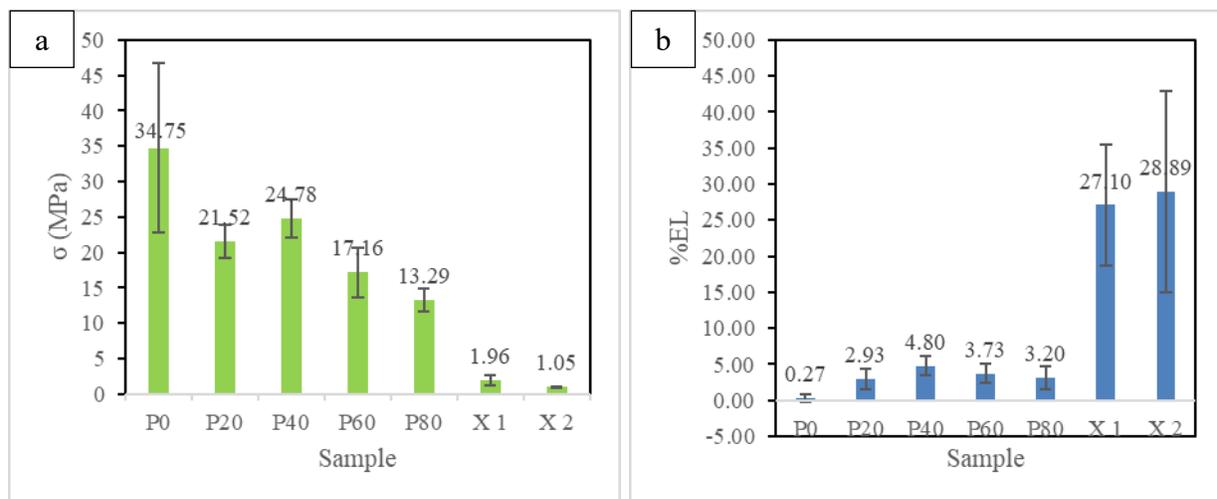

Figure 3. (a) Ultimate tensile strength and (b) percent elongation of sheet mask
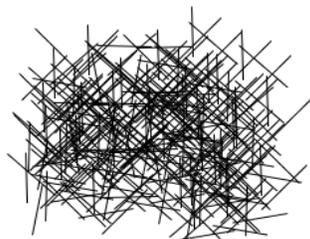

Figure 4. Illustrations of the arrangement of cellulose fibers in sheet face masks

The results of calculating the percent elongation of the sample show an increase in the percent elongation in the P40 sample, with the value of 4.80%, followed by a decrease in the P60 and P80 samples, as depicted in Figure 3(b). Based on these data, it is known that the addition of starch increases the percent elongation of the samples. The addition of starch

contains a plasticizer, a low molecular weight substance, added to enhance film flexibility and processing characteristics. These compounds function by disrupting internal hydrogen bonding networks, which increases intermolecular spacing and reduces intermolecular forces within the polymer structure, hence increasing the percent elongation [33], [34]. After adding starch, the percent elongation value of sheet masks remained lower than that of commercial sheet masks. When subjected to a tensile load, the cellulose fibers in commercial sheet masks will undergo a shift due to the presence of voids in their arrangement, resulting in a higher percentage of elongation values than those of the cellulose-starch sheet mask samples.

Absorption Capability Test

Based on Figure 5, the P0 sample had the highest serum absorption index value for tea leaf extract and hyaluronic acid serum. The addition of starch to cellulose resulted in a decrease in the absorption index value, as evidenced by the increase in mass after adding 20%, 40%, 60%, and 80% w/w starch to the cellulose. The presence of starch between the cellulose fibers reduced the space between fibers, making it more difficult for the serum to fill the space. Compared to the commercial mask, the experimental samples showed a higher absorption index.

Overall, the absorption of the sheet mask samples for the tea leaf extract serum was better than that of the hyaluronic acid serum. This could be due to the difference in the viscosity of the two serums; tea leaf extract serum has a lower viscosity of 1.84 cSt [35], making it more dilute and more easily penetrates the structure of sheet masks, resulting in a higher absorption index of the sheet mask samples produced. Meanwhile, hyaluronic acid has a viscosity of 2.35–3.83 cSt, and the value increases with higher concentrations of hyaluronic acid [36]. Higher viscosity levels substantially reduce the efficiency of mass transfer processes [37].
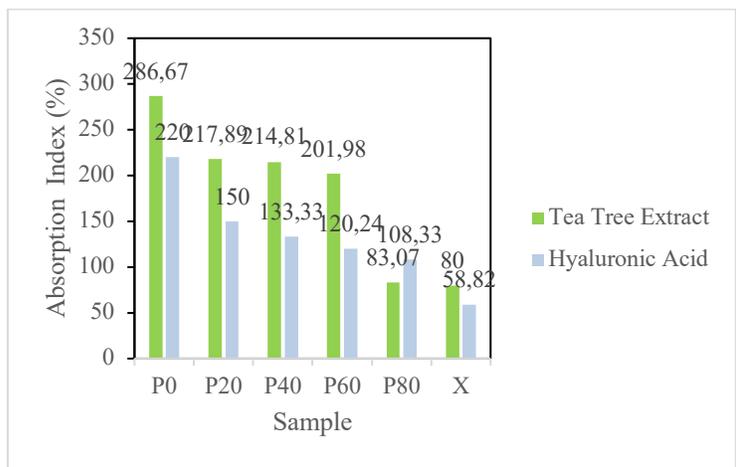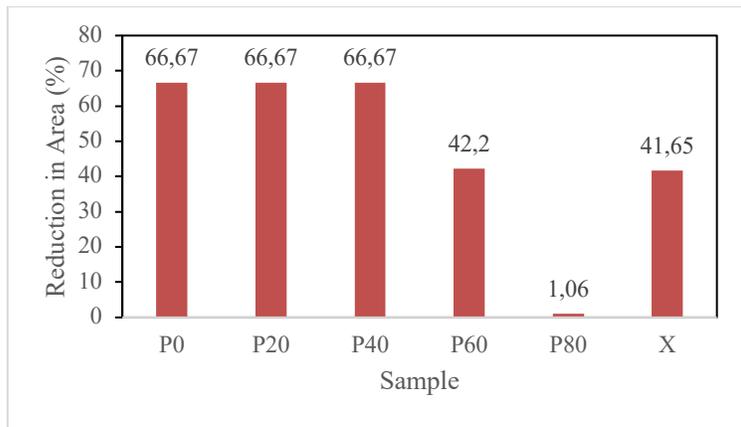
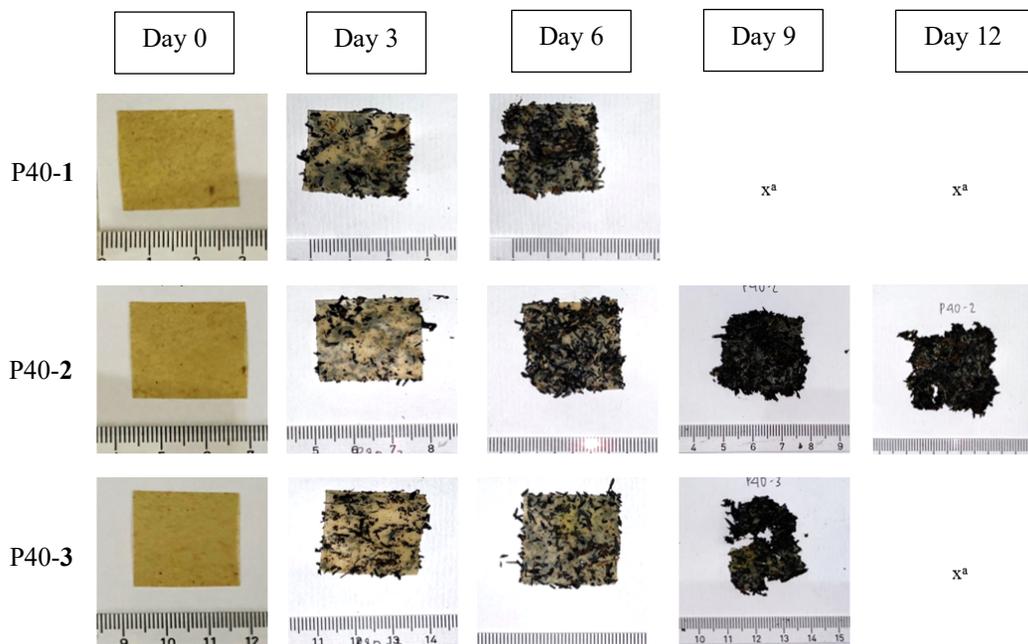

Figure 5. Absorption index of the sheet mask sample

Figure 6. The distribution of data regarding the reduction in the area of sheet mask samples

xᵃ: samples experience 100% biodegradation

Figure 7. The biodegradation test result of the sheet mask samples

Biodegradation Test

The biodegradation test was conducted by soaking samples in tea leaf extract serum for 10 minutes, followed by burial in the soil. The test was carried out under indoor conditions, but still exposed to sunlight. Water is given every two days with the same volume. In this test, the area of the sheet mask samples before and after being buried in the ground is calculated, and then the percentage reduction in area is determined using the ImageJ application.

The characterization results for 12 days showed that all samples experienced biodegradation. The highest reduction in area due to biodegradation occurred in samples P0, P20, and P40, as seen in Figure 6. The biodegradation process is shown in Figure 7. Most of the samples undergo 100% biodegradation in soil for 12 days. Research conducted by Reichert et al. showed that cellulose-starch bio-composites undergo complete biodegradation after 60 days in soil [38]. Compared to samples made of 100% cellulose, starch-containing samples tended to be more difficult to biodegrade, especially samples P60 and P80. Research showed that starch biodegrades faster than cellulose due to its hydrophilic properties that promote water absorption, facilitating the enzymatic degradation [39]. In this research, different behaviours were observed. This occurs because adding starch to the sample increases the sample's mass; therefore, more polymers must be degraded. In comparison to the commercial sheet mask 'X', all samples undergo biodegradation rapidly than the commercial one. Commercial sheet mask 'X' experienced a reduction in area of $41.65 \pm 23.30\%$, and none of its samples underwent complete biodegradation after being buried for 14 days, as shown in Figure 8. It is also caused by the difference in length of the cellulose fiber. In this research, the sheet mask samples consist of discontinuous fibers, resulting in faster biodegradation. The fiber length affects the biodegradation of cellulose. Research showed that amorphous cellulose achieved almost complete hydrolysis in 10 hours, while the high crystallinity cellulose, which was derived from tunicates, exhibits remarkable resistance to biodegradation with only 7.8% hydrolysis occurring after 96 hours of enzymatic treatment [40]. A change in color is also observed, potentially caused by the adsorption of soil particulates or microbial deterioration.

During observation, worms were often found attached to the surface of the sample. The biodegradation mechanism in the soil can be affected by temperature, pH, humidity, and microorganisms. The biodegradation process in soil involves microorganisms. It begins with the colonization of microorganisms on the polymer surfaces, where they establish biofilms, which enhance microbial metabolic activity and create optimal conditions for biopolymer degradation through enzymatic mechanisms, primarily involving oxidation and hydrolysis reactions [41], [42]. Differences in soil characteristics result in different biodegradation mechanisms in various locations and seasons [43]. The soil used in the test was compost soil with a pH of 7, and many earthworms were found in the soil during the sample observation process. On the first day of burying the samples, fewer worms were found during the observation of the samples than on days 3, 6, 9, and 12. The presence of samples buried in the soil caused the worms to grow faster due to an adequate food source. This suggests that the soil conditions are quite fertile, and the presence of microorganisms in the soil facilitates the biodegradation process.
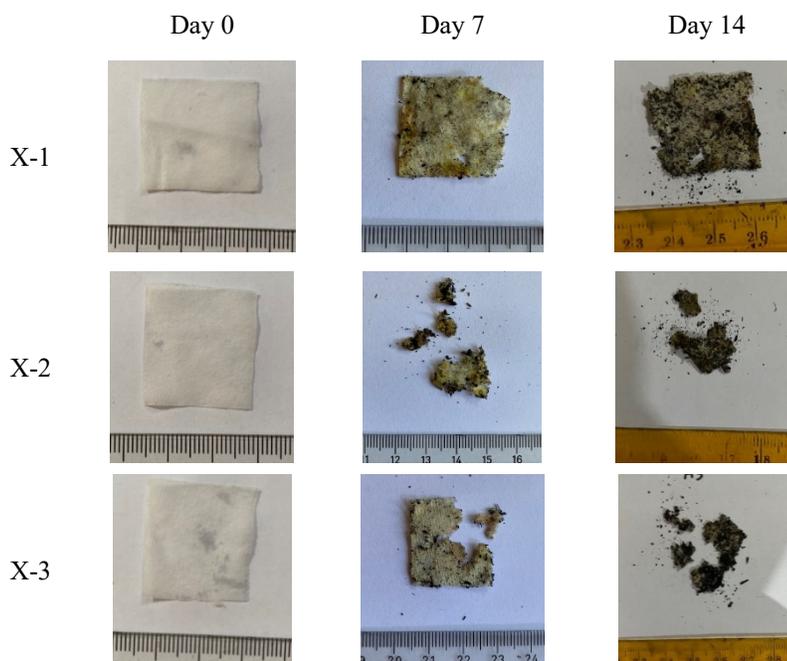
Figure 8. The biodegradation test result of the commercial sheet masks

CONCLUSION

Jicama starch and ginger cellulose were selected for preparing sheets for beauty masks. The materials were chosen because they possess good biodegradability and biocompatibility. The solution casting method is used to produce sheet masks. The tensile strength and percent elongation of the sheet masks are influenced by variations in starch composition. Adding starch to the sheet masks reduces their tensile strength, with the highest tensile strength value obtained with the ratio of cellulose/starch mass of 100:40. All of the samples resulted in higher tensile strength and lower percent elongation in comparison to the commercial sheet mask. The absorption index decreases as the starch content increases, with the highest value of absorption index obtained with pure cellulose samples. After 12 days of biodegradation in soil, the area of the samples is reduced. Most of the samples undergo 100% biodegradation. Samples with a higher composition of starch experience a longer biodegradation process due to the increased mass of the sample from the starch. This research can be used as an alternative in selecting sheet mask materials with flexible properties, high absorption index, biocompatible, and biodegradable, which could reduce the plastic waste from skincare products. For further research, a scanning electron microscope (SEM) evaluation is needed to observe the morphology of the sheet mask. Furthermore, it is essential to conduct a thorough evaluation of the effects of using the sheet mask on the skin, which includes observations on skin health improvement and any potential reactions that may arise.

ACKNOWLEDGEMENT

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