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jmr&t Journal of Materials Research and Technology

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Original Article

Biodegradable plates made of pineapple leaf pulp with biocoatings to improve water resistance

Jutarut Iewkittayakorn[a,*], *Piyaporn Khunthongkaew*[a], *Yutthawee Wongnoipla*[a], *Kaewta Kaewtatip*[b], *Panumas Suybangdum*[c], *Arrisa Sopajarn*[c]

[a] *Department of Molecular Biotechnology and Bioinformatics, Faculty of Science, Prince of Songkla University, Hat Yai, Songkhla, 90112, Thailand*

[b] *Department of Materials Science and Technology, Faculty of Scicence, Prince of Songkla University, Hat Yai, Songkhla, 90112, Thailand*

[c] *Faculty of Agricultural Machinery Engineering, Department of Industrial, Rattaphum College, Rajamangala University of Technology Srivijaya, Rattaphum, Songkhla 90180, Thailand*

ARTICLE INFO

Article history:
Received 25 December 2019
Accepted 6 March 2020
Available online 1 April 2020

Keywords:
Beeswax
Biodegradable
Bio-coating solutions
Chitosan
Pineapple leaf fibers

ABSTRACT

A crucial property of fibrous packaging paper for food is water resistance, while strength properties are also important. To improve these properties, several bio-coating solutions were applied as coatings on paper made of pineapple leaf pulp. The effects of beeswax, chitosan, shellac, alginate/gellan gum and beeswax–chitosan (1% chitosan+4%glycerol+30%beeswax) solutions on pineapple leaf pulp paper were assessed in relation to making biodegradable paper plates. The cooking time (120–180 min) of chemical pulping and the dose of pulp by moist weight (200, 250, and 300 g) to a paper frame ($40 \times 40\ cm^2$) were also studied on making the paper samples. The papers were tested for their physical and mechanical properties. The optimal cooking time and dose of pulp by moist weight found were 180 min and 300 g of pulp per frame, respectively. The bio-coatings increased average grammage and thickness of paper, but gave density reduction from that of uncoated paper. Coating paper with beeswax–chitosan solution gave the longest absorbency time, followed in rank order by alginate/gellan gum, chitosan, beeswax and shellac. The maximum 5.9 kN/m^2 tensile strength was found for paper coated with beeswax–chitosan solution before hot pressing. On comparing papers bio-coated before or after hot pressing, no difference was found in the degradable time with NaAlg/gellan coating, while such difference was observed with beeswax-chitosan coating. The results suggest beeswax–chitosan solution as the best among the alternatives tested, for coating paper to make biodegradable plates.

1. Introduction

Nowadays, plastic food packaging is considered a source of environmental problem wastes, because it takes a very long time to decompose. To address this problem, bio-materials

* *Corresponding author.*
E-mail: jutarut.p@psu.ac.th (J. Iewkittayakorn).

https://doi.org/10.1016/j.jmrt.2020.03.023

have received much attention due to short decomposing times and renewable character. From this perspective, cellulosic fibers are preferred over plastics in food packaging. Thailand is the fourth largest producer and exporter of pineapples [1]. After the harvest a large quantity of residual waste remains in the form of pineapple leaves with high content of cellulosic fibers [2]. This waste has the potential to serve as a source of raw material for making eco-friendly food packaging. For this purpose, the fibers are first pulped before forming into paper, which is then converted to packaging. However, a drawback of cellulosic fibers on producing packaging is the poor water resistance. This aspect could be improved with a suitable bio-coating, which motivated the current study. Several alternative bio-coating solutions were tested as coatings on fibrous paper to improve water resistance. Emulsion-based edible films are favoured for packaging some foods and fruits, and such waterproof film can extend the shelf life of these products [3]. Zhang et al. [4] reported that sodium alginate and gellan gum coating could waterproof paper cups. Beeswax has been widely used as a food grade additive in cosmetics, pharmaceuticals and foods, due to it being a natural commercial wax with high hydrophobicity and excellent moisture resistance. Paper double coating with chitosan–beeswax combination served as a water vapor barrier, as the water vapor transport rate decreased from 171.6 to 52.8 g/m^2/d when concentration of chitosan in solution increased from 1.0 to 3.0 wt%, while the beeswax coating weight was simultaneously reduced (from 10.1 to 4.9 g/m^2) [5]. Khairuddin et al. [6] found that double coating with shellac/starch gave higher water vapor barrier properties on increasing shellac concentration above 50 wt%. This current study is concerned with producing fibrous paper from pineapple leaves, and effects of the alternative bio-coating solutions beeswax, chitosan, shellac, alginate/gellan gum, and beeswax–chitosan (1% chitosan+4%glycerol+30%beeswax) on the paper. On making the base paper, the cooking times (120–180 min) and the pulp weights (200, 250, and 300 g) per paper frame (40 × 40 cm^2) were tested to select an optimal combination, before testing the coatings. The influences on physical and mechanical properties and biodegradation of coating pineapple leaf pulp base paper were also investigated to select the best coating that could benefit making biodegradable plates.

2. Materials and methods

2.1. Materials

Pineapple leaves (*Ananas comosus* (L.) *Merr*., Pattawia) were obtained from the plantation of Pabon community enterprise, Phatthalung province, Thailand. Chitosan powder (CAS number of 9012-76-4) derived from shrimp shells (low molecular weight 50–190 kDa; percentage of deacetylation 75%) and refined beeswax (CAS number: 8012-89-3) were purchased from Sigma-Aldrich Reagent Co., Ltd. Shellac was purchased from Exelacs Co., Ltd. (Bangkok, Thailand). The food-grade sodium alginate (Na^+, 10.22%) and food-grade gellan gum were purchased from Hat-Yai Food Additive Co., Ltd. (Songkhla, Thailand). All other chemicals were of analytical grade.

2.2. Methods

2.2.1. Raw material preparation

Pineapple leaves were cleaned with water to remove dirt and soil particles before drying at room temperature. The leaves were cut into small about 5 cm long pieces. These chopped pineapple leaves were subjected to chemical pulping (soda pulping) at 1 to 4 a ratio of pineapple leaves (kg wet weight) to 10% sodium hydroxide solution (L) [7].

The pineapple leaves were boiled for 120, 150 or 180 min to determine the optimum time for decomposing the leaves to pulp [8]. After that, the pulp was thoroughly washed under running water to remove the residual chemicals. Then the pulp was squeezed to remove water and weighted to 200, 250, and 300 g doses for paper making.

2.2.2. Making paper from the fibrous pulp

Each pulp was mixed with a 50 g/L starch solution and blended in a blender for 5 min. The blended ingredients were placed on the mesh frame of 40 × 40 cm size to make a paper sheet. The paper sheet was then dried for 6 h in a hot air oven at 65 °C [9]. The paper sheet was cut to 20 × 20 cm to test packaging forming using a compression molding machine (VDU-100 model LCC-140) with temperature set at 200 °C and pressure at 200 kg/cm^2 for 10 min; this step is later referred to as “hot pressing”.

2.2.3. Preparation of bio-coating solution and paper surface coating

Five bio-coating solutions were used to coat paper, namely beeswax, chitosan, shellac, alginate/gellan gum solution, and beeswax–chitosan emulsion.

- Beeswax: 20 g beeswax was heated in a 70 °C water bath to completely molten state.
- Chitosan solution: 3 g of chitosan was dissolved in 100 mL of dilute acetic acid (1%v/v) and stirred until complete dissolution.
- Shellac solution: this was in completely dissolved state.
- Sodium alginate/gellan gum solution (NaAlg/gellan): 2%(w/v) sodium alginate (NaAlg) and 1% (w/v) gellan powder were dissolved with 0.5% (w/v) glycerol in distilled water. Then the solution was heated and stirred at 70–80 °C. After that the solution was degassed by sonication [4].
- Beeswax–chitosan emulsion: 1 g chitosan was dissolved in 100 mL of dilute 1% acetic acid solution before adding glycerol to the solution at 4:1 (v/v) ratio. Then beeswax was added in the chitosan solution which was heated to around 80 °C in a water bath for melting the beeswax. The weight of beeswax added was precisely such that it contributed 30 wt% of the emulsion film dry matter. After that, the hot beeswax–chitosan latex was cooled to room temperature [10].

Paper coating: The paper samples were coated using a wire rod coater at constant forward speed to ensure wet film thickness of 250 μm with all coating solutions. The samples were then dried in an oven (65 °C) for 24 h. However, in the case of sodium alginate/gellan solution, before drying the coated

paper in an oven it was sprayed with 5% (w/v) calcium chloride ($CaCl_2$) solution [4].

The bio-coating that gave the highest tensile strength and water resistance was selected for further study of whether to coat before or after the hot pressing.

2.2.4. *Physical and mechanical property testing*

1) Thickness and grammage
   The thickness of the paper was determined using a Vernier caliper. Eight locations on each sample were measured, and the mean thickness was determined with an accuracy of ± 0.001 mm. The grammage of paper was determined according to ISO 536 [11]. Whenever possible, each test piece shall have an area of not less than 500 cm^2 and not more than 1000 cm^2. 20 test pieces were weighted on a balance and masses were recorded to three significant figures. The grammage in grams per square meter was calculated as follows:

$$g = \frac{m}{A} \times 10000 \quad (1)$$

   where m is the mass of the test piece (g) and A is the area of the test piece (cm^2).
2) Absorbency
   The absorbency was measured by placing a paper sample on top of a cavity. 0.01 cm^3 (10 μL) of water was dropped on top of the paper using a micropipette. A stopwatch was immediately started when the preset volume of water was dropped on the paper, and it was stopped when the water droplet was completely imbibed into the paper. This test was repeated five times at different locations on each type of sample [2].
3) Water absorptiveness
   The Cobb method was used to determine water absorptiveness of the paper according to ISO 535 [12]. Five samples of each type of bio-coated paper were kept in the conditioning atmosphere throughout the test. After weighing, the samples were slowly immersed in 100 ± 5 ml water (or proportionately less for a smaller test area) in a cylinder providing 10 mm head space, and the timer was immediately started. Fresh water was used for each determination. The samples were taken out of the liquid, blotted with an absorbent paper to remove excess water, and weighed again. The procedure was repeated until reaching equal masses in two consecutive measurements (during 4 days), and the absorption capacity of the paper was calculated using Eq. (2):

$$\text{water absorptiveness} = (m_2 - m_1)\,F \quad (2)$$

   where m_2 is the wet mass of the test piece (g), m_1 is the dry mass of the test piece (g) and F is 10,000/test area (for a typical test apparatus this is 100 cm^2).
4) Tensile strength
   Tensile strength was tested on an Instron Testing System Model UTM-5582 equipped with a 1 kN capacity load cell. A total of 8 representative test pieces, 25 ± 1 mm wide and 180 ± 2 mm long, were cut from each type of paper and tested to obtain the tensile properties, namely elongation at break, force to break, force at break, time to failure, strain at break and stress at break, from which the tensile strength was determined. The rate of elongation (crosshead speed) was set to 5 mm/min ± 2.5 mm/min [2].
5) Burst strength
   Twenty pieces of bio-coated paper samples (2.5 × 2.5 in.) were used to test burst strength in accordance with ISO 2758 [13]. The specimens were securely clamped in position, with overlap at all points. Hydrostatic pressure was increased as specified until the specimen ruptured, and the maximum pressure was registered. If any movement of the unclamped margin of the specimen was observed, that test run was rejected and clamping pressure was increased. If, however, excessive clamping pressure damaged the specimen, the test result was also disqualified and the clamping pressure was reduced. Each side of the paper was tested ten times.
6) Internal tear resistance of paper (Elmendorf-type method)
   The tear resistance of paper was determined from the average tearing force in accordance with the Elmendorf method [14]. The test pieces were first conditioned in a controlled atmosphere. The two sides of the paper were distinctly marked for distinguishing between them. The bio-coated paper was cut to four rectangular sheets of the same size, between 50 ± 2 mm and 76 ± 2 mm wide and 43 ± 0.5 mm long. A pendulum (with augmenting mass) was used to regulate the energy input and to show the remaining energy by swing amplitude. The mean readings were arranged to within the range 20% to 80% of the full-scale reading by adjusting the mass and the number of sheets tested in a single run. The tear resistance was determined as follows

$$F = \frac{\rightharpoonup Fp}{n}$$

   F is the tearing resistance (mN), $\rightharpoonup F$ is the mean scale reading (mN), p is the number of sheets torn simultaneously for which the pendulum scale has been calibrated to give a direct tearing resistance reading (mN), and n is the number of sheets torn simultaneously.

2.2.5. *The surface morphology analysis by scanning electron microscopy*

Scanning electron microscopy (SEM) was employed to analyze the morphological properties of the paper and the bonding quality between the pineapple leaf fibers and the bio-coating. The surface morphology of uncoated and coated paper was investigated from Scanning Electron Microscope (SEM, JSM-5800 LV, JEOL; Japan) imaging. The surface of the sample was carbon coated and then gold coated for conductivity, and the SEM accelerating voltage used was 20 kV.

2.2.6. *Determination of biodegradation*

Four pieces of each bio-coated type of paper were retrieved every 15 days from where they were buried under soil. Each piece was cleaned from soil debris attached to it. The samples were left overnight to dry at room temperature. The dry samples were placed in a desiccator until a constant weight was reached. The weight of each sample was recorded. The degradation of a sample is expressed as percentage of weight loss [15].

$$\text{Percentage of weight loss} = \left(\frac{\text{Weight of initial sample} - \text{Weight of sample after degradation}}{\text{Weight of initial sample}}\right) \times 100\% \quad (3)$$

2.3. Production of biodegradable plates

The optimum dose of pineapple fiber pulp per mesh frame, for good paper quality after hot pressing, and that bio-coating alternative which gave the best physical and mechanical properties was used in further study of plate forming with a compression molding machine (VDU-100 model LCC-140) operated at 200 °C and a pressure of 200 kg/cm^2 for 10 min.

2.4. Statistical analysis

Two-way analysis of variance (ANOVA) was performed on the instrumental and sensory parameters to evaluate significant differences among the samples at 95% confidence level according to Tukey's test, using SPSS statistical software. This analysis was a multilinear modeling method of pattern recognition, which shows the relationship between the groups on the basis of their distribution in the multidimensional space described by all the variables and also made it possible to determine which variables are principally responsible for the separation of the objects [16].

3. Results and discussion

3.1. Making paper from pineapple leaf pulp

3.1.1. Pulping process

Usually the cooking of pulp is intended to do delignification. The lignin removal depends not only on the decay of ether bonds in lignin macromolecules, but also on the capability of the aqueous solvent solution to dissolve lignin fragments [17]. Table 1 illustrates the characteristics of pineapple leaf pulp produced by boiling pineapple leaves for 120, 150, or 180 min. It was found that the cooking time affects characteristics of the paper. Increasing the cooking time gave smoother paper. 180 min chemical pulping time gave paper with fine structure and no residues of pineapple leaves. When considering the turbidity of the spent liquor after the pulping process, it was found that the turbidity increases with cooking time due to the precipitation of lignin on the surface of the fibers, in agreement with Xu et.al. [17] and Laftah and Rahaman [18]. Thus, 180 min was selected as the optimum alkaline cooking time.

3.1.2. The grammage and thickness

Paper products are categorized by their grammage, which is the mass per unit area. The grammage of handmade paper can be varied by increasing or decreasing the amount of pulp used for one sheet, and this will affect the paper thickness along with other physical properties of the paper [19]. The weight and thickness of paper samples made of pineapple leaf pulp are shown in Table 2. The dry weight and thickness of paper per sheet increased with amount of pulp used per sheet. The paper formed with 200 g per sheet was torn during forming, being too thin for the poor formation. 250 g per sheet gave soft and flexible paper. 300 g per sheet gave stable and strong paper, and this pulp dose of 300 g per sheet was selected for further study.

Table 1 – Characteristics of paper made from pineapple leaf pulp cooked for various times.

Boiling time	Characteristics of paper from pineapple leaf pulp	
120 min	Texture of paper is coarse and it has many residues of pineapple leaves.	
150 min	Texture of paper is medium and it has some residues of pineapple leaves.	
180 min	Texture of paper is fine and no residues of pineapple leaves	

3.2. Physical and mechanical properties of bio-coated paper samples

3.2.1. Tensile strength and water barrier properties

The paper made from pineapple leaf pulp boiled for 180 min at 300 g per sheet (40 × 40cm^2) was coated with five alternative bio-coating solutions, namely beeswax, chitosan, shellac, NaAlg/gellan solution and beeswax–chitosan emulsion before hot pressing. 6 samples of each type of coated paper were tested for tensile strength using the universal testing machine. The tensile strengths are shown in Fig. 1(a). It was found that all other coatings except for chitosan improved tensile strength from that of the uncoated base paper. The beeswax-chitosan solution gave the highest tensile strength of 5.91 kN/m followed by the shellac coated cases (5.53 kN/m) without a statistically significant difference. The beeswax-chitosan solution gave the highest tensile strength because the coating film deposited on paper has mechanical strength [20]. The other types of coating were not fully absorbed either, leaving a thin coating. Regarding water resistance, it was observed that papers coated with chitosan, NaAlg/gellan and beeswax-chitosan solutions gave improved water resistance over the uncoated base paper. The paper coated with NaAlg/gellan solution had the highest water resistance, agreeing with Papageorgiou et al. [21] who reported that a combination of NaAlg/gellan crosslinked with calcium ions could form a stable film by hydrogen and ionic bonds having good water barrier properties. The beeswax and shellac coatings did not have measurable water resistance as the water was immediately absorbed. The tested types of coating differed

Table 2 – Grammage, thickness of and characteristics of paper samples from pineapple leaf pulp.

Wet weight of pineapple pulp (g)	Grammage of paper (g/ m^2)	Thickness of paper (mm.)	Characteristics of paper after forming testing
200	420.188 ± 2.46	1.490 ± 0.078	
250	500.854 ± 2.669	1.810 ± 0.115	
300	603.875 ± 2.826	2.170 ± 0.233	

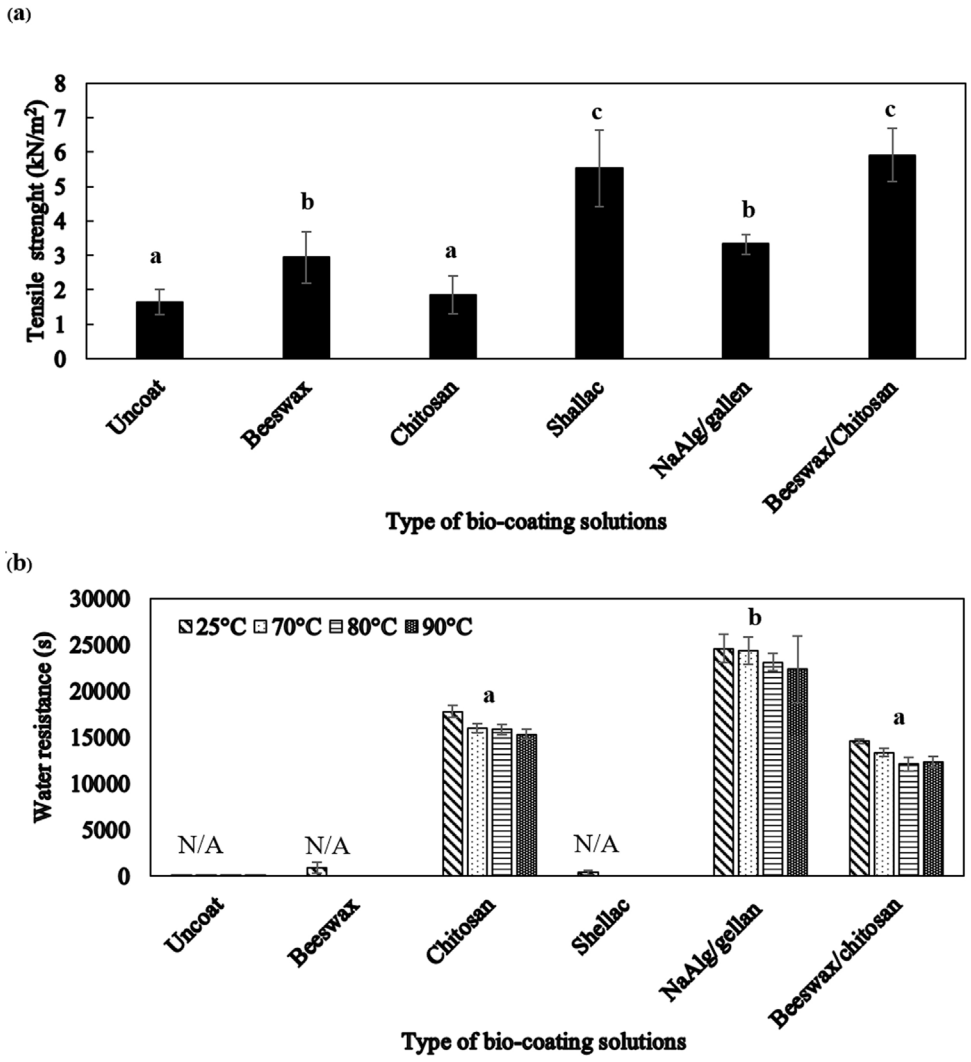


Fig. 1 – Properties of bio-coated papers made from pineapple leaf pulp. (a) Tensile strength, and (b) water resistance.

statistically significantly. The effect of water temperature on paper absorption was also investigated. It was found that different test temperatures had no significant effects as shown in Fig. 1(b).

The NaAlg/gellan and beeswax–chitosan coatings gave better physical properties than the other tested coatings. Both of these coatings were then tested for coating before or after hot pressing with the workflow shown in Fig. 2. The blend ratio in the beeswax–chitosan emulsion was also explored, with beeswax contents 0, 30% and 60% w/w.

3.3. *Effect of coating process on physical properties of coated paper*

3.3.1. *Grammage, thickness and density*

It was found that paper coated with the bio-coating solutions had a higher average grammage and thickness along with a lower density than the uncoated base paper, as shown in Table 3. This indicates that the coating film contributed to both mass and thickness. It was also found that the paper coated before hot pressing had a lower grammage and density (with larger thickness) than paper coated after the hot pressing. This might be due to some decomposition of the bio-coating during hot pressing seen as mass loss, while the added moisture before hot pressing caused evaporation that added bulk (i.e., reduced density and increased thickness).

3.3.2. *Tensile strength*

From Fig. 3, it was found that paper coated with the bio-coating solutions before hot pressing had a higher average tensile strength than the uncoated base paper, and also had average tensile strength higher than after hot pressing, except for the paper coated with 1% chitosan+4%glycerol+60%beeswax. This might be because hot pressing after coating can force the coating into the bulk paper, while hot pressing before coating smoothens the top surface of the paper. The maximum tensile strength of 5.9 kN/m was found with 1% chitosan+4%glycerol+30%beeswax coating applied before compression. The lowest tensile strength of 2.851 kN/m was recorded for the paper coated with NaAlg/gellan solution after compression. This indicates that the beeswax–chitosan solution gave better bond strength than the NaAlg/gellan solution between the cellulose fibers. Increasing the beeswax fraction in beeswax-chitosan emulsion did not increase the tensile strength, because hydrophobic lipids can act as effective barriers to moisture but are inferior in structural strength. For example, Zhang et al. [10] reported that increasing lipid in a lipid–hydrocolloid emulsion based film could improve its water vapor barrier properties, but also reduced the mechanical strength. Composite films with a high lipid content will give poor structural properties and low mechanical strength. Moreover, two-way ANOVA found no significant difference in tensile strength between coating before or after hot pressing at 95% confidence level.

3.3.3. *Absorbency*

The absorbency of bio-coated paper samples is shown in Fig. 4. It was found that all coated papers gave higher absorbency time than the un-coated base paper, indicating that all the coatings somewhat repelled water. The beeswax–chitosan

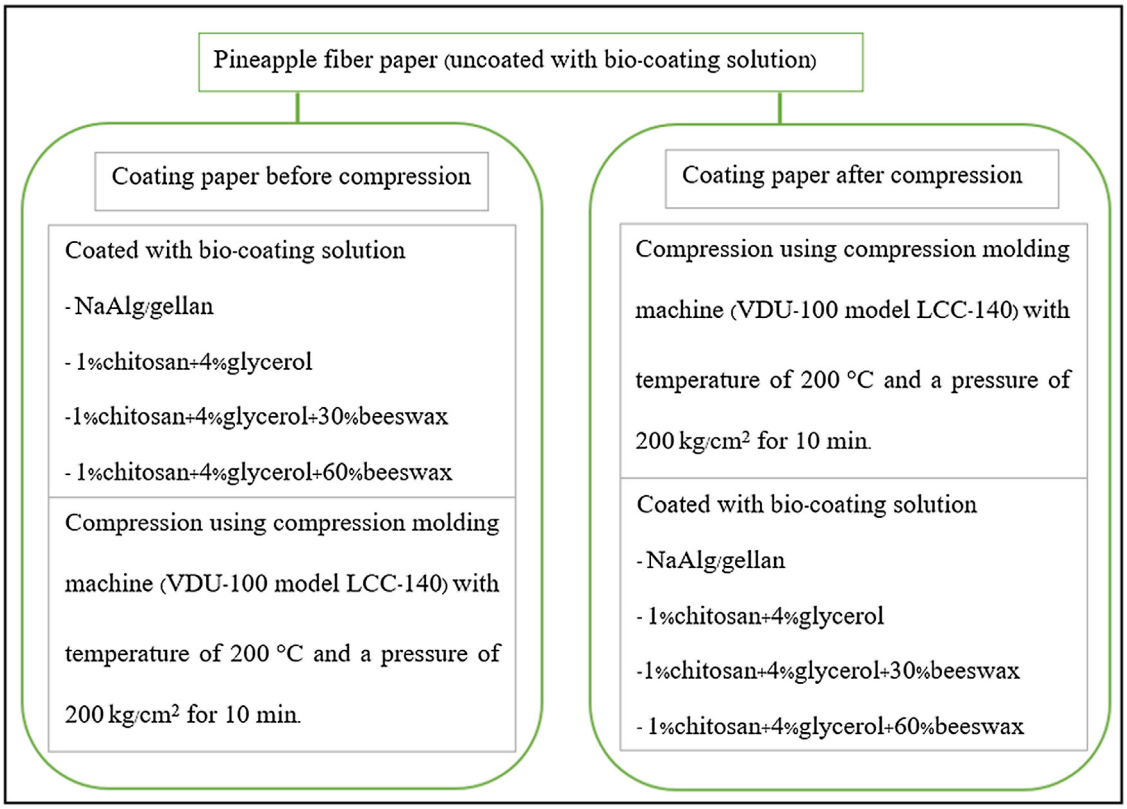


Fig. 2 – Testing NaAlg/gellan and beeswax–chitosan coatings on paper made of pineapple leaf pulp.

Table 3 – Average grammage, thickness and density of bio-coated paper made of pineapple leaf pulp.

Type of paper	Type of bio-coating	Grammage (g/m^2)	Thickness (mm)	Density (kg/m^3)
Uncoated	No coating	720.64	0.77	936.17
Coating before compression	NaAlg/gellan	793.00	1.19	669.49
	1%chitosan+4%glycerol (1% C+4% G)	724.73	0.99	722.75
	1%chitosan+4%glycerol+30%beeswax (1% C+4% G+30% B)	748.34	1.22	662.33
	1%chitosan+4%glycerol+60%beeswax (1% C+4% G+60% B)	765.33	0.96	766.57
Coating after compression	NaAlg/gellan	819.27	0.84	878.38
	1%chitosan+4%glycerol (1% C+4% G)	728.22	0.81	901.00
	1%chitosan+4%glycerol+30%beeswax (1% C+4% G+30% B)	761.26	0.79	968.03
	1%chitosan+4%glycerol+60%beeswax (1% C+4% G+30% B)	774.97	0.80	982.92

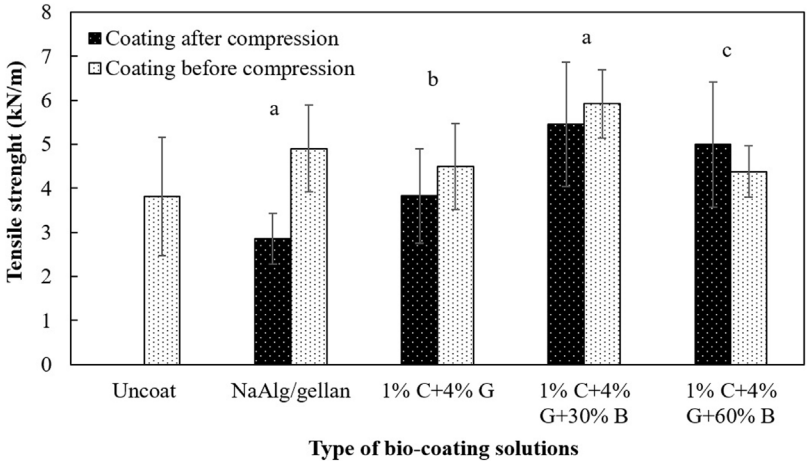


Fig. 3 – Tensile properties of bio-coated paper made of pineapple leaf pulp.

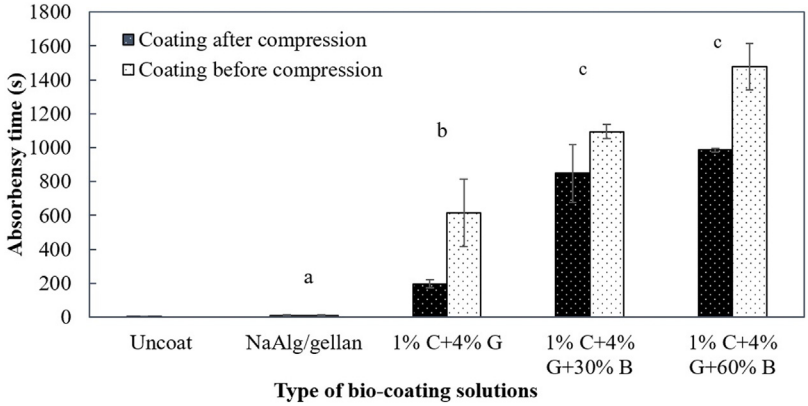


Fig. 4 – The absorbency time of coated papers made of pineapple leaf pulp.

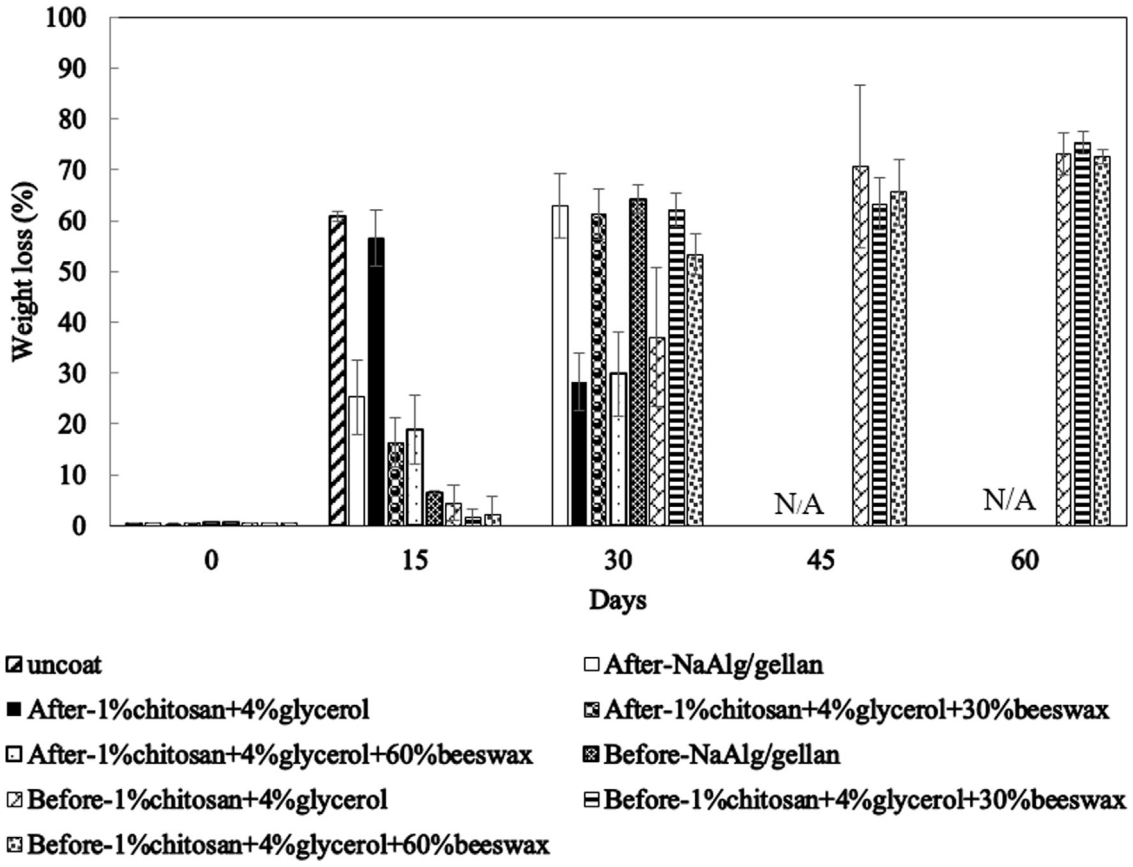


Fig. 5 – Physical changes in paper made of pineapple leaf pulp with different bio-coatings, during degradation for 60 days while buried in soil.

solution gave a higher absorbency time than the NaAlg/gellan solution. This might be because chitosan has an excellent emulsifier capacity to prepare stable lipid latexes, due to electrostatic interactions between positively-charged chitosan with negatively-charged lipids or beeswax [22]. Further, beeswax is rich in lipids that resist water, increasing the absorbency time more than NaAlg/gellan solution that has only calcium ions as a crosslinking agent and plasticizer to enhance water resistance [23]. Monedero et al. [24] also reported that lipids are usually applied to enhance water-repellency in a coating, due to their strong hydrophobicity. In addition, the absorbency time increased when increasing beeswax content in beeswax-chitosan solution, because this increased the lipid content. ANOVA found no significant difference in absorbency between paper coated before or after hot pressing, at 95% confidence level.

3.4. *Biodegradation of paper*

The biodegradation of 25 × 25 mm samples of each type of paper made with pineapple leaf pulp was investigated for 60 days. The degradation was characterized by the average weight loss of paper after being buried in the soil for 15 days and the results are shown in Figs. 5 and 6. The uncoated paper was the fastest to become completely decomposed, within 30 days. This could be because pineapple leaf pulp was formed into paper without any crosslinking agent or film coating. In comparison, when papers bio-coated before or after hot pressing were compared, no difference in degradation time was found for paper coated with NaAlg/gellan solution, but a difference was there for beeswax-chitosan coated cases. Paper coated after hot pressing with beeswax-chitosan degraded faster that that coated before hot pressing. This is because after compression the bio-coating solution coated only the paper surface, but when coated before hot pressing the solution was heated and compressed into the bulk paper, inducing crosslinking that gave resistance to microbial digestion and degradation.

3.5. *Morphology of paper from pineapple leaf pulp by scanning electron microscopy*

Scanning electron microscopy, SEM, was used to study the surface morphology of the un-coated paper and the paper samples with bio-coatings, and the images are shown in Fig. 7(a) and (b). It is clear that the bio-coatings filled pores between the cellulose fibers, leading to high tensile strength and increased water resistance. It was also found that bio-coating before hot pressing covered the fibers to a higher extent than coating after hot pressing. Hot pressing after coat-

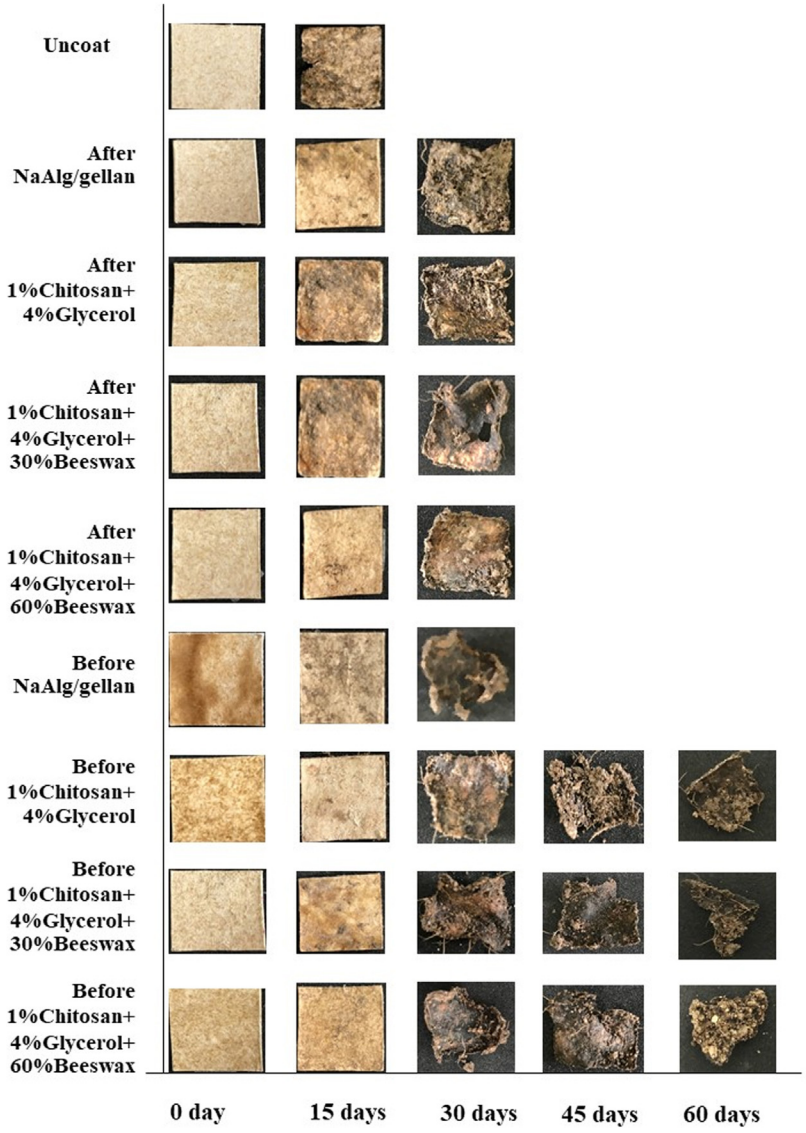


Fig. 6 – Degradation of the pineapple leaf pulp papers with different bio-coatings shown in photos taken every 15 days.

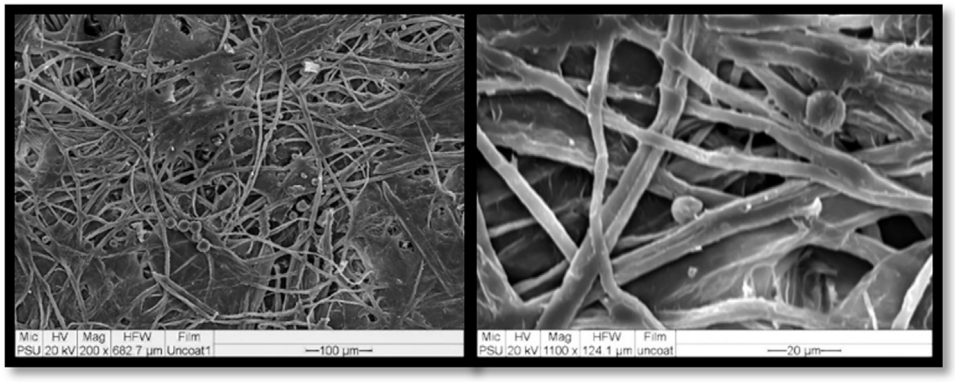
ing forced the coating into the bulk paper, instead of leaving it only in a surface layer on top of the paper.

3.6. *Production of biodegradable plates*

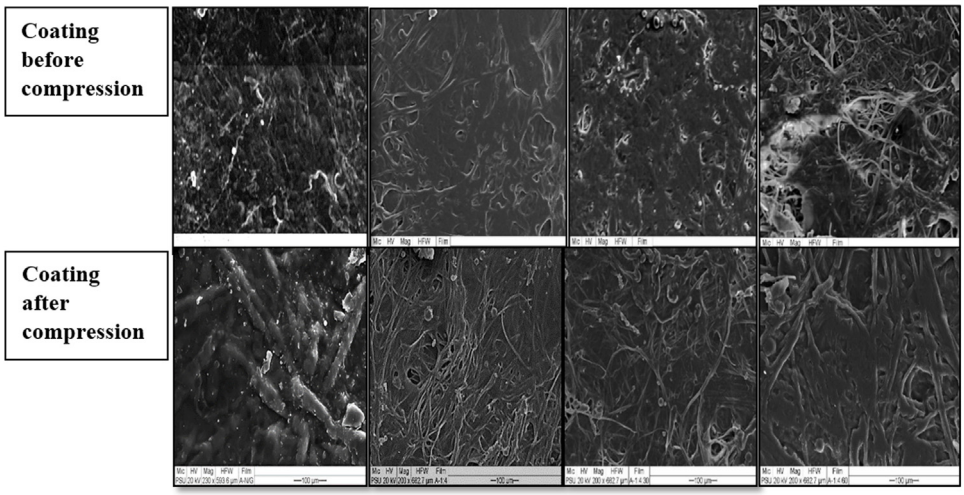
The pineapple leaf pulp paper was coated with solution of 1%chitosan+4%glycerol+30%beeswax before compression to form biodegradable plates, as shown in Fig. 8. The plate grammage, thickness and density were 750.01 g/m^2, 1.24 mm, 670.55 kg/m^3.

4. Conclusion

It was found that paper made of pineapple leaf pulp when coated with a bio-coating had improved physical and mechanical properties. This was attributed to bonding due to improved tensile strength, burst, and tear resistance; and the water absorbency was higher than of paper made of pineapple leaf pulp without coating. The highest absorbency (353 g/m^2) was found for paper coated with 1%chitosan+4%glycerol+60%beeswax before hot pressing, and the lowest (163 g/m^2) was for paper coated with 1%chitosan+4%glycerol+30%beeswax after hot pressing. Hot pressing after coating with 1%chitosan+4%glycerol+30%beeswax gave the the highest 5.914 kN/m tensile strength and 6784 mN tear resistance, followed by the paper hot pressed before coating with 1%chitosan+4%glycerol+30%beeswax in tensile strength ranking, while 6435 mN tear resistance was found on compressing before coating with NaAlg/gellan. The highest 477 kPa burst strength was found by hot pressing before coating with 1%chitosan+4%glycerol+30%beeswax. The results overall demonstrate that pineapple leaf pulp can be used in biodegradable packaging to reduce the use of plastics. At the same time such value-added use of natural fibers reduces a waste stream and its contribution to landfill.



(a) Morphology of pineapple leaf pulp paper.



(b) Morphology of pineapple leaf fiber paper with bio-coating solution.

Fig. 7 – Morphology of uncoated pineapple leaf pulp paper and similar paper coated with bio-coating solutions.

Fig. 8 – Biodegradable packaging from pineapple leaves with bio-coating solutions.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This research was supported by grants from the Prince of Songkla University (PSU grant SCI610603S). Gratefully acknowledged for their kind supports are also the Department

of Molecular Biotechnology and Bioinformatics, PSU Faculty of Science. Also thanks to Publication Clinic service by the Research and Development office (RDO), PSU and Assoc. Prof. Dr. Seppo Karrila for assistance in manuscript preparation.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.jmrt.2020.03.023.

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