

# Physical, Mechanical and Antibacterial Properties of Biodegradable Bioplastics from Polylactic Acid and Corncob Fibers with Added Nano Titanium Dioxide

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## Abstract

The objective of this research was to investigate the mechanical, physical and antibacterial activities and biodegradability properties of bioplastics from polylactic acid (PLA) and corncob fibers (CF). The bioplastics were prepared by mixing PLA and CF at different ratios (100:0, 90:10, 80:20, 70:30, 60:40 and 50:50 % w:w) in the internal mixer and molding was done by using the hot-compressing molding method. The results demonstrated the decrease in tensile strength and elongation at break with increased in CF. Young's modulus was found to be highest in the 70 %PLA: 30 %CF bioplastic, however, it decreased when the CF was increased. The hardness and water absorption were dependent on CF concentration. SEM analysis revealed the well dispersion of CF in PLA matrix. PLA matrix and increasing of CF induced in CF agglomeration. To develop PLA/CF plastic for antibacterial food packaging application, its antibacterial activity was conducted. The antibacterial determination revealed that 70 %PLA: 30 %CF containing 2 % TiO<sub>2</sub> bioplastic exhibited the highest inhibition against *E. Coli*, *S. aureus* and *B. subtilis*. Additionally, the biodegradable character of the bioplastic was dependent on concentration and time, as the bioplastic weight loss was increased when the concentration of CF and biodegradation period were increased. The results obtained from this research indicate that the bioplastics prepared from polylactic acid and corncob fibers is biodegradable bioplastics and can be used as alternate synthetic plastics. The bioplastic with 2 %TiO<sub>2</sub> added can be utilized potentially for expected antibacterial food packaging.

**Keywords:** Biodegradable, Bioplastics, Polylactic acid, Corncob fibers, Nano titanium dioxide, Mixing PLA and CF, Antibacterial

## Introduction

Packaging is a bundle of something enclosed, wrapped, canned or boxed to aid product handling, usage and protect the products. More than fifty percent of packaging is for food products. To prevent the food products from contamination or infection caused by MOs and to keep the product safe some specialized food packaging was done e.g. aseptic packaging, vacuum packaging etc. Generally, foods are packaged with plastic or petroleum derived material dominates in the market. The plastic raw materials are polymers which have advantages including good mechanical properties. However, the plastic packaging waste causes serious worldwide problems. Due to the major problems from these plastics are their negative environmental impacts including the oceans, posing a threat to aquatic life, agricultural lands, and are not easily degradable, therefore the development.

Edible plastics is a type of thermoplastic which is considered as biodegradable polyester, produced by the polymerization of bio-derived monomers such as corn starch, tapioca roots, chips, sugarcane, potatoes, jack fruit seeds, and waste products from food or agriculture industry [1-4]. It is one of the most frequently used thermoplastic bioplastics. It has similar physical and mechanical properties to synthetic plastics, like PET and PS or PE [5-7]. PLA is a leading biomaterial for the packaging industry that is replacing conventional petrochemical-based polymers, that is using in food packaging applications [8]. However, it is very brittle, low deformation at break, high modulus, and hydrophilic properties, which limits its application. [9,10].

Bioplastics are generally biodegradable, use many different renewable sources such as vegetable oil, corn starch, potato starch, fibers from pineapple, jute, hemp, henequen leaves and banana stems [11,12]

and being considered in the world as the 4.0 revolution of green technology. Due to the low mechanical properties, several studies have been carried out to improve the bioplastics performance. Natural fibers have been widely used for reinforcing polymers attributed to their sustainable nature, biodegradability and low cost compared to synthetic fibers [13]. Natural fibers are added to increase the strength of bioplastics and accelerate the degradation process, are environmentally friendly and offer other advantages, including recyclability, relatively higher specific strength and stiffness [14,15].

Some studies suggested that, fiber administration promotes fiber-matrix adhesion by changing their physical, chemical, thermal, and mechanical properties [16]. Several types of starch blends (mixture of tapioca, rice starch, oxidized wood pulp fiber, potato starch and yam starch and avocado seeds) are using to increase the bioplastic properties of the packaging [17-20]. Bioplastic fabrication processes can cause numbers of pollutants, because the by-products are used in field as fertilizers and pesticides. Additionally, its environmental friendliness and high potential added value promise to be a material for the future [21].

Corn cob is one of the most common agricultural wastes. It has been utilized and developed to be the beneficial and expected materials. In Thailand, corn cob is largely available, relatively inexpensive and often discarded. Corn cob fibers have been used as a source for starch due to their large availability, low price and high starch capacity. Dried and ground corn cobs possess high total dietary fiber content and have been reported to exhibit relatively high water holding capacity and high oil absorption ability [22]. Lignin-containing cellulose nanofibril from corn cobs has been reported to exert good potential as reinforcement filler in bioplastic matrix [23]. This paragraph was set for the explanation “why the corn cob fiber was used in this research”.

Antimicrobial properties are major developments in bioplastic packaging [24]. PLA has been documented to be successfully incorporated with antimicrobial substances to develop antimicrobial characteristics [25]. Several studies revealed that, some metal oxide exhibits antifungal and antibacterial properties against spoilage organisms. Titanium dioxide ( $\text{TiO}_2$ ) is one of the attractive compounds which show special features, such as easy control, non-toxicity and good resistance to chemical erosion these properties allow its application for different functions, including antibacterial agents. It exhibits antimicrobial activity, principally against gram-positive bacteria such as *Escherichia coli* and *Staphylococcus aureus* [26].

To reduce the environmental impacts of synthetic plastics by using an appropriated bioplastics, therefore the present research was established to investigate the bioplastics prepared from the different concentrations of polylactic acid and corn cob fibers for their mechanical and physical properties, biodegradability, and antibacterial activity.

## Materials and methods

The mechanical, physical, antibacterial properties and biodegradability of PLA and CF bioplastic was carried out as follows:

### Preparation of corn cob fibers

The corn cobs were collected from the corn fields in Pathum Thani province, Thailand. The preparation of corn cob fibers was carried out according to Garadimani *et al.* [27] with slight modifications. Clean and dried corn cobs were washed with tap water to remove dirt and other impurities, and then treated with 10 %NaOH solution for 24 h. After treatment, corn cobs were washed with distilled water to eliminate excessive NaOH solution. After that, the corn cobs were ground in hammer mill and appropriate sieves were used to get the required particle size of 175 - 212  $\mu\text{m}$  [27].

### Preparation of bioplastics from polylactic acid and corn cob fibers, PLA/CF

The bioplastics, PLA/CF were prepared by mixing PLA and CF with different ratios (100:0, 90:10, 80:20, 70:30, 60:40 and 50:50 % w:w). The fabrication process was performed by mixing the ingredients in polymer internal mixer at the temperature of 190 °C at 50 rpm. Thereafter, the bioplastics were ground and molded uniformly using hot compression molding at 190 °C in accordance with the ASTM D638 and ASTM D2240 standards. The molding was carried out for 13 min (5 min for heating, 5 min for compressing and 5 min for cooling).

### Determination of mechanical properties

The mechanical properties, including tensile strength, elongation at break, and Young's modulus, of the bioplastics specimens were performed according to the conditional standard test method for tensile properties (ASTM D638) and an electronic universal testing machine (UTM) with a constant tension of 50

mm/min was employed. Determination of mechanical properties of the specimen was conducted as previous described [28,29] with slight modifications. The tests were established on 5 specimens for each sample.

#### ***Tensile strength***

Tensile strength is defined as the maximum force that can be held by the specimen when stretched or pulled before the material is broken. Tensile strength was calculated with the following equation:

$$\text{Tensile strength} = \frac{F_M}{A_0}$$

$F_M$  is the maximum stress (N),  $A_0$  is the material cross-sectional area (mm<sup>2</sup>), and the unit of tensile strength is MPa.

#### ***Elongation at break***

Elongation at break is an extension of a material when tested tensile until finally fracture. The elongation at break was quantified by the following equation:

$$\text{Elongation at break} = \frac{L-L_0}{L_0} \times 100$$

$L$  is the final elongation of the material (mm), and  $L_0$  is the initial length of the material (mm).

#### ***Young's modulus***

Young's modulus is a measure of stiffness to elastic deformation under load. Young's modulus (in MPa) was calculated with the following equation:

$$\text{Young's modulus} = \frac{\sigma_2 - \sigma_1}{\varepsilon_2 - \varepsilon_1}$$

$\varepsilon_1$  and  $\varepsilon_2$  are the condition of relative elongation at 0.05 and 0.25 %, respectively.  $\sigma_1$  and  $\sigma_2$  are the stress that occurs at  $\varepsilon_1$  and  $\varepsilon_2$ , respectively. The Young's modulus unit is MPa.

### **Determination of physical properties**

#### ***Hardness***

The hardness of a material signifies how resistant it is to abrasion, indentation, scratching, and plastic deformation under compressive load. In this research, the Shore D hardness test was conducted base on the standard ASTM method D2240. The size and thickness of the specimen setting at least 6 mm thickness and at 12 mm from each rim was determined under the conditioned temperature and humidity of the standard method, ASTM D2240. The Shore Durometer, model GS-612/G-S-720 under compressive of 5 kg was employed. The hardness test was performed as previous research [30] with minor modifications. At least 5 specimens for each sample were tested.

#### ***Water absorption***

The tested bioplastics were dried at 70 °C for 24 h. A known weight ( $W_0$ ) of the bioplastics after drying was subjected to 24 h water immersion with continuous agitation. After the experimental time, they were removed from the water, cleaned of adhered water and their weight ( $W_t$ ) were determined. The percentage water absorption was calculated using the following equation:

$$\text{Water absorption (Wt \%)} = \frac{W_t - W_0}{W_0} \times 100$$

#### ***Morphological examination***

The microstructural features of the specimens were examined using Scanning Electron Microscope (SEM). Before conducting SEM, the specimens were layered with gold to prevent unnecessary charging before the SEM examination with an accelerating voltage of 10 kV [31,32].

#### ***Biodegradability test***

The biodegradability test was performed based on the soil burial method [33,34] with modifications. The bioplastic specimens, 10×30×3 mm<sup>3</sup>, were weighed ( $W_0$ ) after oven-drying at 70 °C for 24 h. The known weight specimens were buried in aerated and moisture soil for 7, 15, 30, 45, and 60 days. After the

set duration, the specimens were unburied, cleaned, and weighed ( $W_t$ ) after they were oven-dried at 70 °C 24 h. The weighing was conducted until the constant weight was occurred. The biodegradability as a function of bioplastic weight loss (WL) was calculated using the following equation:

$$WL (\%) = \frac{W_0 - W_t}{W_0} \times 100$$

#### Determination of antibacterial property

PLA/CF with TiO<sub>2</sub> nanoparticles (NPs) added has not yet been studied for its antimicrobial activity. Therefore, antimicrobial activity of PLA/CF added with TiO<sub>2</sub> NPs on inhibition of bacteria growth is needed to investigate.

In this research, antimicrobial property of the PLA/CF bioplastics, with the addition of different concentrations (0.0, 0.5, 1.0, 1.5 and 2.0 %) of TiO<sub>2</sub>, was carried out using pathogenic microbial strains, *Escherichia coli* (a type of Gram-negative bacteria) and *Staphylococcus aureus* and *Bacillus subtilis* (a type of Gram-positive bacteria). The determinations were conducted using an agar diffusion method and based on the formation of inhibition zones on microbial growth media according to previous studies [35-37] with modifications. The microorganisms were inoculated into 50 mL of nutrient broth culture medium in 100 mL Erlenmeyer flask and incubated in rotary shaker at a temperature of (28 ± 2 °C) for 24 h. After incubation period, 1 % (v/v) of inoculum was inoculated into agar medium and mixed thoroughly. A pour plate method was employed by transferring a volume of 20 mL of the microbial mixtures into a sterilized plate. After solidification, the circular specimens of the tested bioplastics were placed on the agar. The plates were later incubated at 37 °C for 48 h. After incubation, the scales were used to measure the diameter of the inhibition zone (mm).

#### Statistical analysis

Data obtained were analyzed through the program SPSS. A significant difference in level was determined using one-way analysis of variance (ANOVA) and Duncan's Multiple Range Test. The  $p < 0.05$  was used to determine the differences among treated mean values.

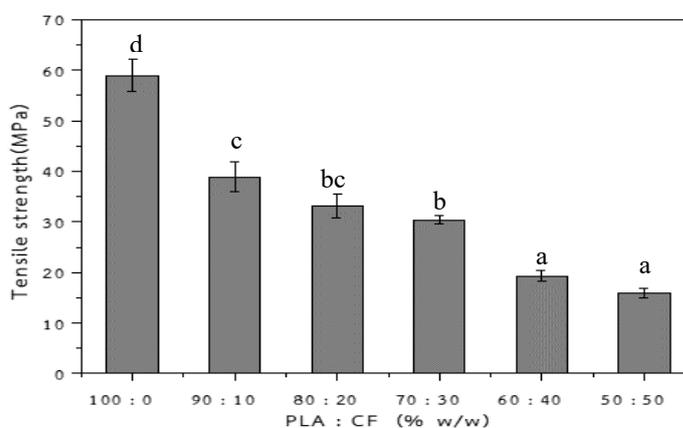
#### Results and discussion

The results from the investigation on mechanical and physical properties, biodegradability of the bioplastics prepared from the different concentrations of polylactic acid (PLA) and corncob fibers (CF), and antibacterial property with added TiO<sub>2</sub> are as follows;

#### Mechanical and physical properties of bioplastics, PLA/CF

##### Tensile strength

Bioplastic packaging material needs some toughness to endure load-bearing pressure. This toughness may be evaluated by the physico-tensile properties of bioplastic such as tensile strength. Tensile strength is the maximum force that a material specimen can resist under tension [38].



**Figure 1** Tensile strength (MPa) of bioplastic prepared from polylactic acid (PLA) and corncob fibers (CF) with different ratios (100:0, 90:10, 80:20, 70:30, 60:40, and 50:50 % w:w). Data are shown as mean ± SEM (n = 3). Bars having different letters are significantly different at  $p < 0.05$ .

**Figure 1** depicts that, the tensile strength of the bioplastics prepared from PLA and CF with different concentrations (100:0, 90:10, 80:20, 70:30, 60:40 and 50:50 % w:w) and evaluated according to standard ASTM D638 method using Universal testing machine (UTM).

Based on **Figure 1**, on one hand, the tensile strength was increased significantly with increased PLA as the 100 %PLA: 0 %CF bioplastic exhibited the highest tensile strength (60 MPa). On the other hand, the tensile strength was decreased significantly (18 MPa) with increased CF as the 50 %PLA: 50 %CF bioplastic exhibited the lowest tensile strength, indicating the tensile strength of the PLA/CF bioplastic was concentration dependent manner.

This result is showed linear character with the physical and mechanical properties of corn-based bioplastics films with different starch and glycerol content, which demonstrated that the concentration of starch increased, with the increasing of tensile strength [28]. Furthermore, corn-based films with 10 % concentration of corn starch and glycerol possessed poor tensile strength at 0.5 MPa. However, several studies have been documented that, the decrease of tensile strength in the bioplastic as a response to the increase of plasticizers concentration [39-41]. Bioplastic based on arrowroot starch with glycerol plasticizer and ZnO fillers produced tensile strength of 5, 9966 MPa [42]. The difference in the results could be due to the method of bioplastic preparation, nature of filler, and matrix used [33]. Thus, the properties and application of the bioplastics, PLA/CF can be maximized by optimizing the concentration of the PLA and CF.

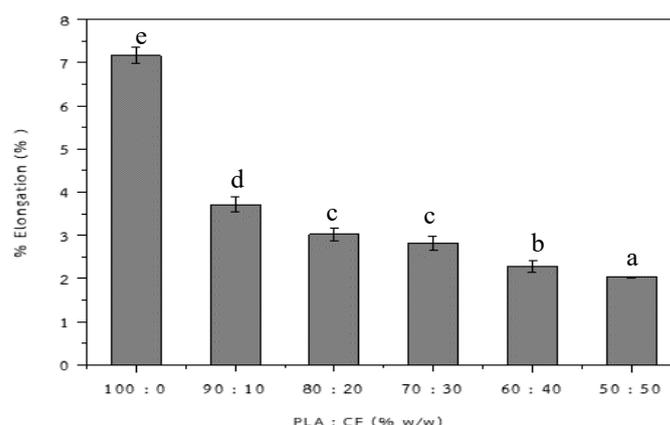
### **Elongation at break**

Elongation is the change in length of a material resulting from tensile stress. Elongation at break is the indication of the amount of the variation of extreme plastic length while attaining tensile strength until the plastic breaks, related to the original length.

**Figure 2** shows the elongation at break (%) of the PLA/CF bioplastic. The elongation at break was found to be highest in the 100 %PLA: 0 %CF bioplastic, but to be lowest in the 50 %PLA: 50 %CF bioplastic. This result indicated that the elongation at break of the tested bioplastic was influenced by the concentration. It was decreased when the concentration of PLA was decreased and the concentration of CF was increased. This similar result was found in the previous study which showed that increasing the concentration of starch caused a reduction of elongation of break [28]. In addition, decrease elongation at break of FG-plasticized films was occurred when the plasticizer concentration was increased [31]. Nevertheless, the opposite effect was observed when other types of plasticizers were used [31].

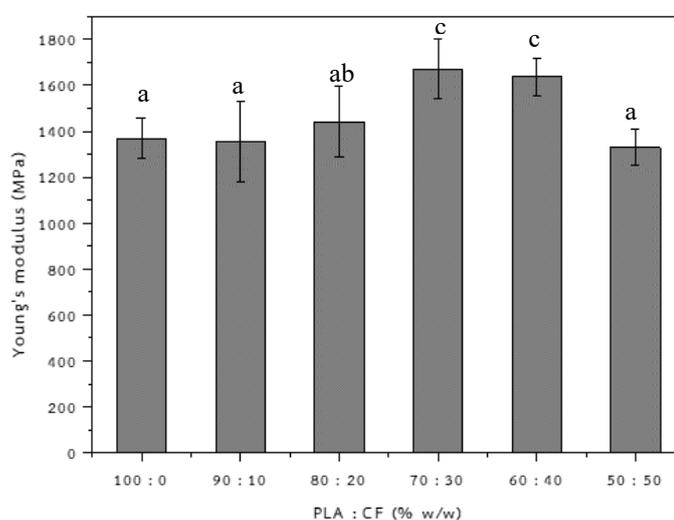
### **Young's modulus**

Young's modulus is a measure of stiffness to elastic deformation under load. Higher values of Young's modulus corresponding to stiffer material where it requires higher loads to elastically deform, whereas lower Young's modulus corresponding to flexible material where it requires lower loads to elastically deform [43].



**Figure 2** Elongation at break (%) of bioplastic prepared from polylactic acid (PLA) and corncob fibers (CF) with different concentrations (100:0, 90:10, 80:20,70:30, 60:40 and 50:50 % w:w). Data are shown as mean  $\pm$  SEM (n = 3). Bars having different letters are significantly different at  $p < 0.05$ .

**Figure 3** shows the fluctuation of Young's modulus of the PLA/CF bioplastics prepared from different concentrations (100 :0, 90:10, 80:20, 70:30, 60:40, and 50:50 % w:w). The Young's modulus was slightly increased when the lower concentration of PLA (90 and 80 %) and CF (10 and 20 %) was employed. The highest Young's modulus (1,750\_MPa) was occurred in the 70 %PLA: 30 %CF bioplastic. However, they were declined when lower concentration of PLA (60 and 50 %) and higher concentration of CF (40 and 50 %) were administered. Munthoub and Rahman [44] found that the concentration of glycerol increased, the Young's modulus value was found to be decreased. Variation of the Young's modulus in this research is likely influenced by the concentration of CF. The 70 %PLA: 30 %CF bioplastic exhibited the higher Young's modulus than 100 %PLA: 0 %CF, indicating the CF is a reinforced bioplastic. As increase CF (60 %PLA: 40 %CF and 50 %PLA: 50 %CF) induced the agglomeration of CF, which evidenced by SEM determination in **Figures 9 - 11**, leading to a reduction of the Young's modulus. This result is concomitant with several studies, such as a reduction in the mechanical properties as the amount of the added filler increased [45], increasing corncob content led to increase in moduli, but it started to deteriorate at a high level of powder content [46] and the addition of PBAT (poly butylene-adipate-co-terephthalate) leads to a decrease of the elastic modulus in the tensile strength of the blends [47].

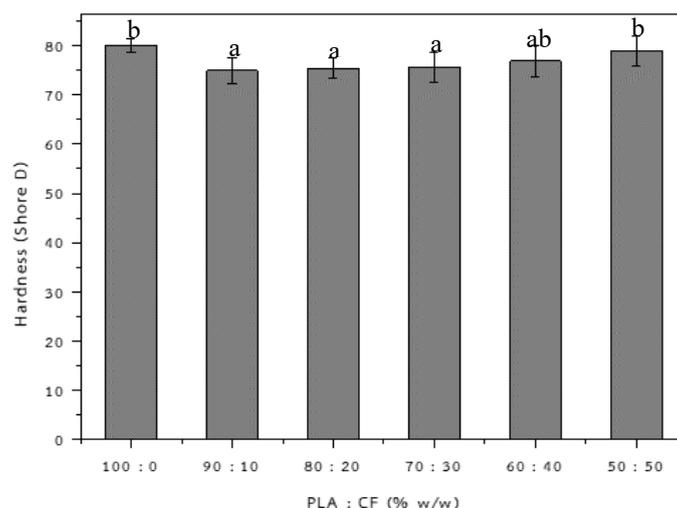


**Figure 3** Young's modulus (MPa) of bioplastic prepared from polylactic acid (PLA) and corncob fibers (CF) with different concentrations (100:0, 90:10, 80:20,70:30, 60:40 and 50:50 %w:w). Data are shown as mean  $\pm$  SEM (n = 3). Bars having different letters are significantly different at  $p < 0.05$ .

### Physical property

#### Hardness

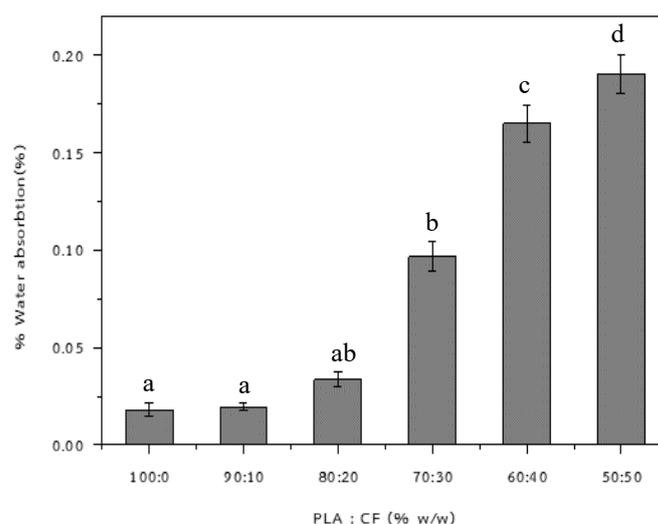
**Figure 4** depicts the hardness of PLA/CF bioplastics, at various concentrations (100:0, 90:10, 80:20, 70:30, 60:40, and 50:50 %w:w). The hardness test carried out using Shore Durometer model GS-612 revealed that the hardness of 100 %PLA: 0%CF bioplastic was 79.51D. Increased concentration of CF, slightly increased the hardness as the hardness of the PLA/CF at the concentrations of 90:10, 80:20, 70:30, 60:40, and 50:50 %w:w was found to be 74.35, 75.13, 75.86, 76.46, and 78.40, respectively. This finding is in line with the corn cob particles and E-glass fibers reinforced hybrid epoxy composites exhibited superior properties. Moreover, Nguyen *et al.* [48] found that the hardness of the fabricated bioplastic was positively proportional to the ratio of the starch.



**Figure 4** Hardness (MPa) of bioplastic prepared from polylactic acid (PLA) and corncob fibers (CF) with different concentrations (100:0, 90:10, 80:20,70:30, 60:40, and 50:50 %w:w). Data are shown as mean  $\pm$  SEM (n = 3). Bars having different letters are significantly different at  $p < 0.05$ .

#### Water absorption

**Figure 5** reveals the water absorption test of the tested bioplastics. The percentage water absorption of the bioplastics was found to be concentration dependently. It was increased with the increase CF concentration. The water absorption of the 50 %PLA: 50%CF bioplastic exhibited the highest water absorption. This finding indicates that the water absorption ability of the bioplastics is likely due to high total fiber content of CF which has been found to exhibit relatively high water holding capacity and high oil absorption ability [22]. Zhu *et al.* [46] reinforced high-density polyethylene (HDPE) by corn cob powder and found that increasing corncob content led to an increase in the water absorption of the composite. However, this result is opposed to the previous researches, such as by Pietrosanto *et al.* [47] which demonstrated that an increase in the concentration of plasticizers (rice starch), water absorption was reduced. A decrease in water absorption has also been reported when silica was added during bioplastic production [49]. A reduction in water uptake with an increase in the added microcrystalline cellulose has been previously observed [50]. The difference in the results could be due to the method of bioplastic preparation, nature of filler and matrix used [33].

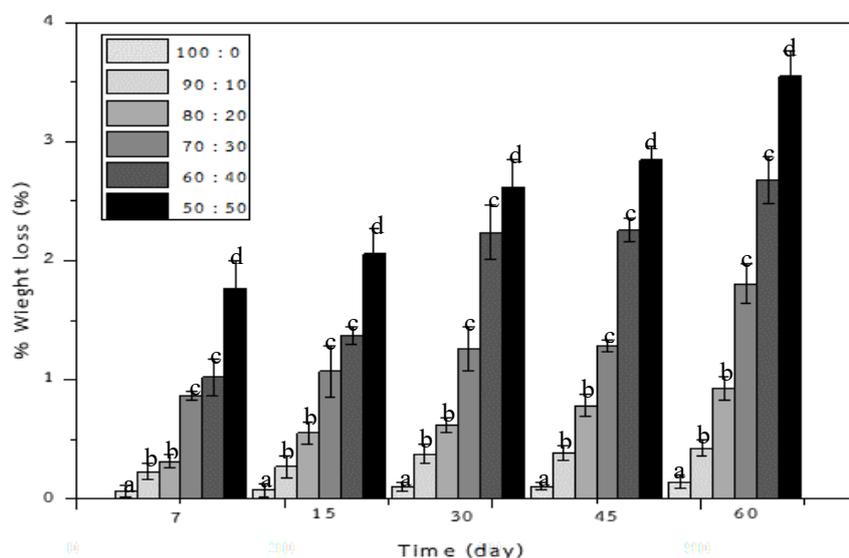


**Figure 5** Water absorption (%) of the bioplastic prepared from polylactic acid (PLA) and corncob fibers (CF) with different concentrations (100:0, 90:10, 80:20,70:30, 60:40, and 50:50 % w:w). Data are shown as mean  $\pm$  SEM (n = 3). Bars having different letters are significantly different at  $p < 0.05$ .

### Biodegradability test

The accumulation of plastic products worldwide causes substantial hazardous pollution which is mainly due to they are not easily degradable materials. Nevertheless, the major advantages of bioplastics are their biodegradability [51].

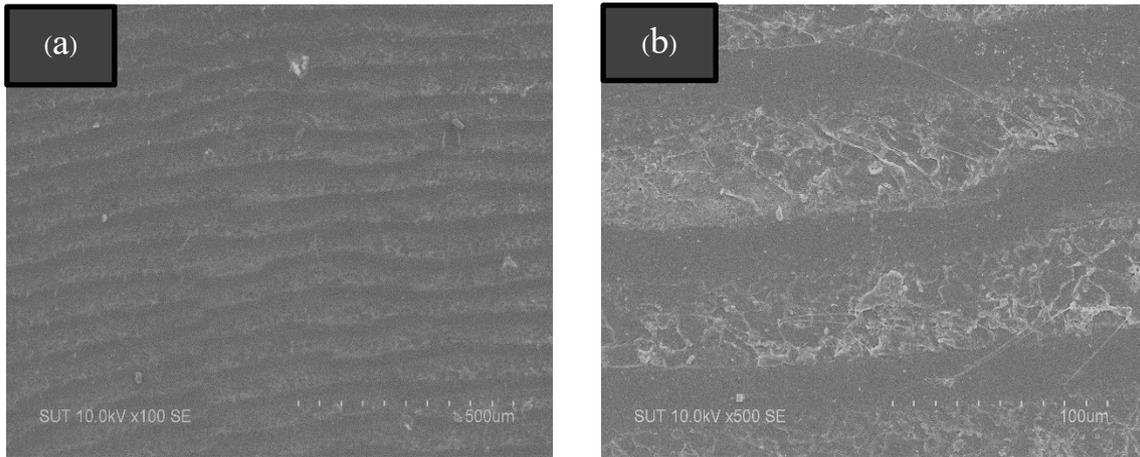
In this research, the biodegradability of the PLA/CF bioplastics tested as a function of weight loss (%) using the soil burial method is presented in **Figure 6**. The biodegradability was increased with the increasing CF, but the decreasing PLA, as the 50 %PLA: 50%CF bioplastic exhibited the highest, meanwhile the 100 %PLA: 0 %CF showed the lowest biodegradability. This indicating the biodegradability of the bioplastics is a concentration dependent manner. An also, the biodegradability is time dependently as the highest biodegradability was occurred when the highest experimental time for 60 days was carried out. From the above results, it may be concluded that biodegradability of the tested bioplastics tested is affected by the CF concentration and the degraded period. Bioplastics of renewable origin are compostable or degradable by micro-organisms [52]. In addition, the bioplastics prepared from polylactic acid and corncob fibers which are biodegradable. The degradation of the bioplastics occurred due to PLA is biodegradable polyester produced through polymerization of lactic acid that can be decomposed. Increase biodegradability with increase corncob fibers is due to corncob fiber is a natural material which can be degraded. There has been demonstrated that natural fiber reinforced composites are biodegradable [53,54] and accelerate the degradation process [55]. This finding is in line with a study on the biodegradability of arrowroot starch-based bioplastics with additional ZnO on soil shows a decrease in the bioplastic.



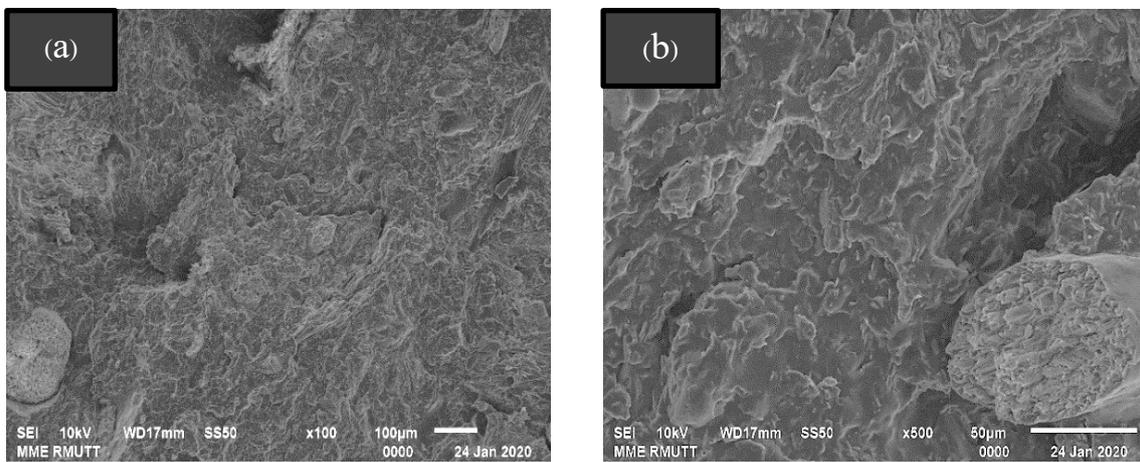
**Figure 6** Biodegradability (% weight loss) of bioplastics prepared from poly(lactic acid) (PLA) and corncob fibers (CF) with different concentrations (100:0, 90:10, 80:20, 70:30, 60:40, and 50:50 %w:w). Data are shown as mean  $\pm$  SEM (n = 3). Bars having different letters are significantly different at  $p < 0.05$ .

### Morphological examination

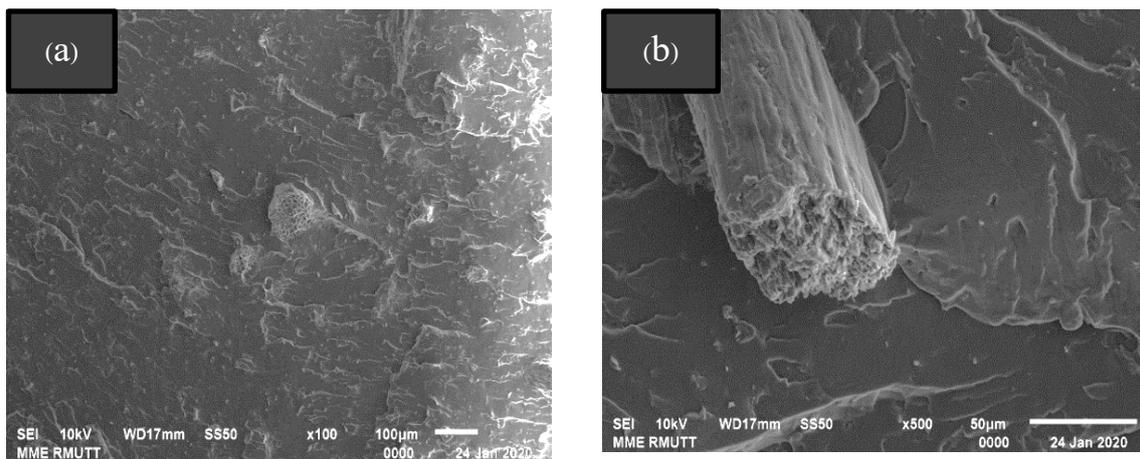
The morphological examination using SEM revealed that the bioplastic specimens exhibited variation surface structures. The 100 %PLA: 0 %CF bioplastic demonstrated a uniform homogenous polymer of PLA with the smooth surface (**Figure 7**). Increase CF in the 90 %PLA: 10 %CF (**Figure 8**) and 80 %PLA: 20%CF (**Figure 9**) bioplastics induced the good dispersion of CF in PLA matrix, indicating the good CF - PLA matrix adhesion. However, increase CF in the 70 %PLA: 30 %CF (**Figure 9**), 60 %PLA: 40 %CF (**Figure 10**) and 50 %PLA: 50%CF (**Figure 11**) bioplastics exhibited rough surface structures with the presence of CF agglomeration and poor interfacial adhesion. Amin et al found that bioplastics synthesized using titanium dioxide nanoparticles with corn starch caused the increase roughness with the decrease uniformity of the starch bioplastic [56]. This occurrence corresponds to the decrease mechanical property of PLA/CF bioplastic with increase CF. The hydrophilic nature of natural fibers adversely affects adhesion to a hydrophobic matrix, resulting in poor strength properties has been documented [57]. Overall, the results suggested that, the appropriate concentrations of PLA: CF led to enhance the coherence and integrity in the surface structure of the bioplastics.



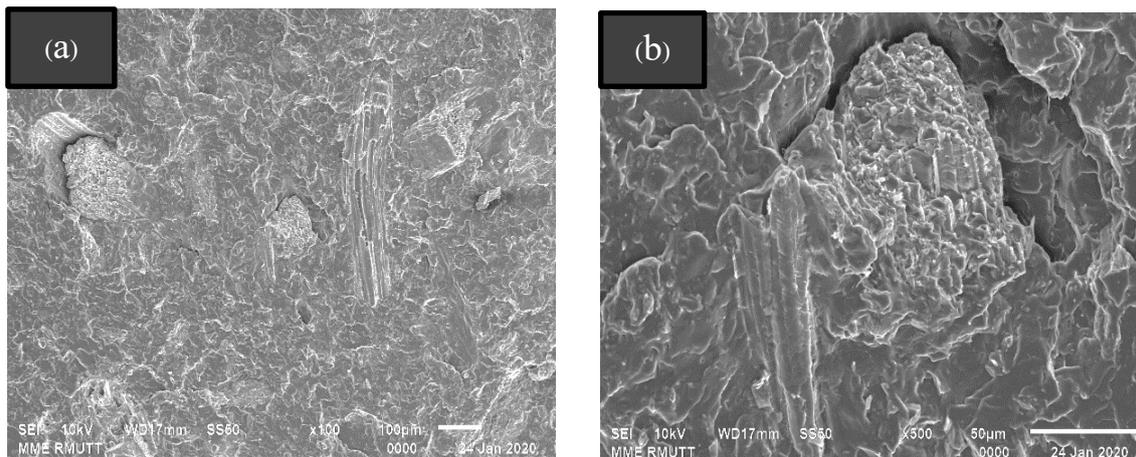
**Figure 7** Field emission SME of bioplastic, 100 %PLA: 0 %CF with (a) 100 times (100×), (b) 500 times (500×) magnification.



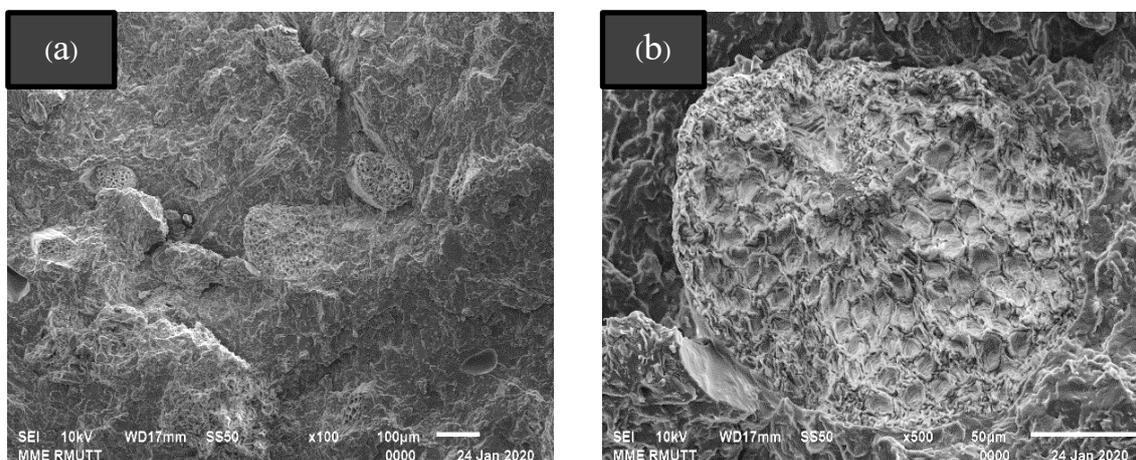
**Figure 8** Field emission SME of bioplastic, 90%PLA: 10% CF with (a) 100 times (100×), (b) 500 times (500×) magnification.



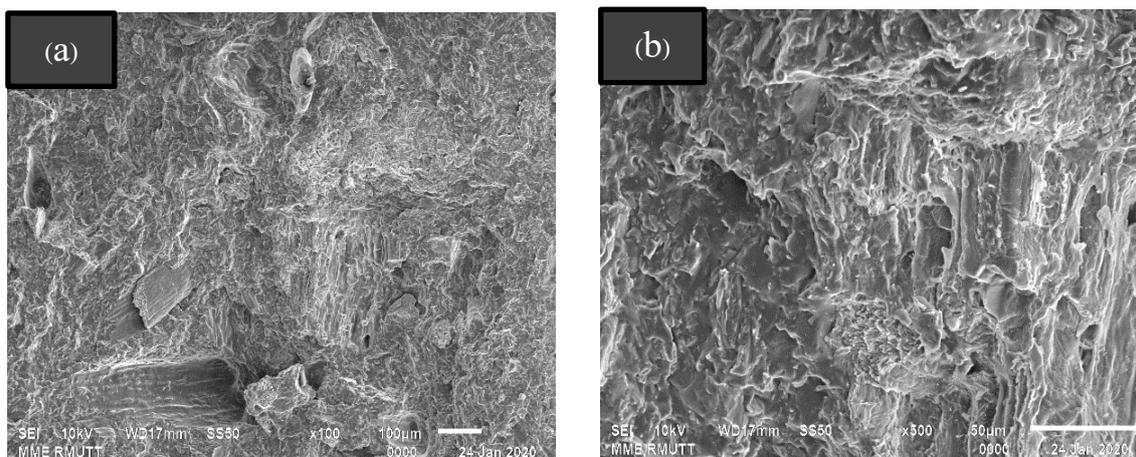
**Figure 9** Field emission SME of bioplastic, 80 %PLA: 20 %CF with (a) 100 times (100×), (b) 500 times (500×) magnification.



**Figure 10** Field emission SME of bioplastic, 70 %PLA: 30 %CF with (a) 100 times (100×), (b) 500 times (500×) magnification.



**Figure 11** Field emission SME of bioplastic, 60 %PLA: 40 %CF with (a) 100 times (100×), (b) 500 times (500×) magnification.



**Figure 12** Field emission SME of bioplastic, 50 %PLA: 50 %CF with (a) 100 times (100×), (b) 500 times (500×) magnification.

### Antibacterial property

The 70 %PLA: 30 %CF bioplastic was utilized further to investigate the antibacterial property, because this bioplastic showed better mechanical and physical performance. The antibacterial property of the 70 %PLA: 30 %CF bioplastic with the addition of various concentrations (0.0, 0.5, 1.0, 1.5, and 2.0 %) of titanium dioxide (TiO<sub>2</sub>) was conducted. *Bacillus subtilis*, *Staphylococcus aureus* and *Escherichia coli* were the bacterial used.

The result revealed that, the 70 %PLA: 30 %CF bioplastic with added TiO<sub>2</sub> inhibited the bacterial growth where there was no inhibition of the bacterial growth found in control (without adding TiO<sub>2</sub>). However, the bioplastic with of 0.5 %TiO<sub>2</sub> did not exhibit to inhibition against *B. subtilis* and *E. coli*. The inhibition zone was 38 mm for *B. subtilis*, 30 mm for *S. aureus* ad 20 mm for *E. coli* when 2 %TiO<sub>2</sub> was administered. This indicates that, the antibacterial activity is dependent on the amount of TiO<sub>2</sub>.

**Table 1** Antibacterial property of the PLA/CF bioplastics with various TiO<sub>2</sub> additive concentrations via inhibition on bacterial growth.

TiO <sub>2</sub> added (%)	Inhibition on bacterial growth		
	<i>Bacillus subtilis</i>	<i>Staphylococcus aureus</i>	<i>Escherichia coli</i>
0.0	0	0	0
0.5	0	10	0
1.0	13	12	11
1.5	20	17	14
2.0	38	30	20

From the table, the bioplastic mixed with TiO<sub>2</sub> showed the antibacterial activity against both gram positive and gram negative bacteria. TiO<sub>2</sub> nano-materials display microbicidal effect to different diseases-causing organisms, such as *S. Aureus* [58], *E. Coli* [59], *P. aeruginosa*, *E. faecalis* [60] and *L. helveticus* [61]. The bioplastic from PLA/CF with added TiO<sub>2</sub> exhibits antimicrobial activity due to antibacterial properties of TiO<sub>2</sub> [59]. NPs can directly contact with the bacterial cell wall, without the need to penetrate the cell [62,63]. According to the study in Jayaseelan *et al.* [64], the antibacterial mechanisms of TiO<sub>2</sub> NPs involving the release of positively charge ions to react thiol group of the proteins on the cytoplasmic membrane leading to rapture the cell wall and increased in permeability, which led to cell death [65]. TiO<sub>2</sub> NPs favor the inactivation of microorganisms due to their strong oxidizing power by free radical generation, such as hydroxyl and superoxide anion radicals, showing reductions growth against several microorganisms, such as *E. coli* and *S. aureus* bacteria [26]. TiO<sub>2</sub> is commonly associated to reactive oxygen species (ROS) and affect bacterial cells by different mechanisms leading to their death [64,66]. Application of a TiO<sub>2</sub> coating on implants reveals that the coating inhibits the adhesion and growth of *Streptococcus mutans*, *S. epidermis* and *E. coli* around the implants [67].

### Conclusions

In conclusion, the bioplastic prepared from polylactic acid and corncob fibers with the ratio of 70 % polylactic acid and 30 % corncob fibers exhibits the optimal tensile strength, elongation at break, Young's modulus, hardness, water absorption and biodegradability. Moreover, this bioplastic with the addition of 2 %TiO<sub>2</sub> displays the highest antibacterial property. Due to the bioplastic comprises 70 % polylactic acid and 30 % corncob fibers possesses the optimal mechanical and physical properties and also exerts antibacterial activity when 2 %TiO<sub>2</sub> is added, this bioplastic therefore can be an appropriate alternative for food packaging material.

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