Physical and Functional Properties of Durian Skin Fiber Biocomposite Films Filled with Natural Antimicrobial Agents

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Effects of durian skin fiber (DSF), epoxidized palm oil (EPO), and cinnamon essential oil (CEO) on the physical and functional properties of polylactic acid (PLA) biocomposite films were investigated. The biocomposite films were produced *via* a solution casting process. The results indicated that the PLA with 3 wt.% DSF absorbed the maximum amount of water (5.9%), which was due to the hydrophilic characteristics of the DSF. Additionally, PLA and DSF lost the most weight after decomposing for 50 days in soil. The dart drop impact test showed a reduction in the impact failure weight of the PLA composites with EPO and CEO, which could have been because of their porosity; hence, a porosity was created between the microstructures. Interestingly, the tear resistance was remarkably amplified for the biocomposites with EPO and CEO. From the migration study, the PLA, DSF, EPO, and CEO biocomposite film appeared to be suitable for use as food packaging for all types of food, as there were no negative effects when they were tested with aqueous, alcoholic, acidic, fatty, and milk food product types.

Keywords: Antimicrobial; Active food packaging; Biocomposite film; Durian skin fibers

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INTRODUCTION

There is an increased demand for better hygiene and more stringent safety in food security for both fresh and processed food products, and there is demand for cost-effective ways to extend the shelf-life of a product. As a result, an active food packaging approach is being researched for the rapid development of film-forming materials (Kerry *et al.* 2006; Gyawali and Ibrahim 2014). Active food packaging refers to the incorporation of certain additives into the packaging system with the goal of maintaining or extending the product quality and shelf-life. Active packaging includes packaging with antimicrobial agents that are either natural or synthetic to enhance the freshness of food products. Vodnar *et al.* (2015) and Salgado *et al.* (2015) reported that the utilization of antimicrobial packaging has more advantages compared with the direct addition of antimicrobial agents to food products. With antimicrobial packaging, the package that contains the active agent may be removed before the product is consumed, so that the antimicrobial agent will not be ingested with the product.

Natural antimicrobial agents, which have potential and current value for use in foods as a secondary preservative, have recently been reviewed (Tajkarimi *et al.* 2010). Furthermore, the use of natural additives as a food preservative has become popular among

consumers because of their awareness and concern for the negative side effects of synthetic chemical additives found in food products. Gutierrez *et al.* (2009) reported the presence of bioactive compounds in plants that possessed antimicrobial properties with resistance to a wide range of pathogenic bacteria and spoilage of raw food. A number of compounds from various plant sources were reported to have an antimicrobial activity, such as terpenoids, alkaloids, flavonoids, tannins, and phenols (Ababutain 2013). For instance, cinnamic aldehyde and eugenol, which are found in cinnamon extract, have an antimicrobial activity against both gram-negative and gram-positive bacteria (Yadav and Singh 2004).

Active food packaging also relates to biodegradable food packaging because the biodegradation of the bio-film occurs as it is attacked by microorganisms that are present in the environment. The optimum formulations of commercial biofilms have shown excellent gas barrier properties, although their barrier performance is dramatically reduced in the presence of moisture and/or other plasticizers that are necessary to form materials adequate for processing. Manshor *et al.* (2014) and Nur Aimi *et al.* (2015) added the valuable properties of durian skin fiber (DSF) into biopolymer, *via* the incorporation of DSF as a micro- and nano-sized filler in polylactic acid (PLA) and polypropylene (PP) composites. However, further improvement of these composites was needed to overcome the current increasing consumer demand for safer, environmentally friendly, and higher quality products. Polylactic acid is one of the most promising biopolymers derived from 100% renewable sources and is an alternative solution for consumer packaging because of its excellent biocompatibility and biodegradability (Abdulkhani *et al.* 2014). Polylactic acid is also used as a bio-absorbable polymer for bone fixation devices because of its mechanical property profile, thermoplastic possibility, and biological properties (Xiao *et al.* 2012). However, PLA is very brittle and has limited gas barrier properties, which prevents it from completely accessing the industrial sectors, such as packaging (Dong *et al.* 2014). Considering these disadvantages of PLA and its high cost, it is not surprising that PLA has not received more attention. The introduction of natural fibers into PLA composites could possibly overcome the problems mentioned above. A hydrophobic behavior was reported by Siti Nur Ezzati *et al.* (2018), whereby PP/DSNF layer improved composite performance in decreasing the amount of water absorption with coupling agent (MAPP) addition.

The mechanical and thermal properties of reinforced PLA composites *via* melt blending have long been investigated and reported in the literature. The incorporation of nanoclay into PLA composites to improve the barrier properties has been widely studied. However, very limited information is available on utilizing durian skin as a reinforcement in biocomposites. Besides, the processability of PLA can be increased with plasticizers that contribute to enhance the polymer chain flexibility (Ali *et al.* 2016). Among the natural plasticizer, epoxidized palm oil (EPO) is favourable plant oil due to its characteristics such as low cost, non-toxicity, and availability as a renewable agriculture resource. Additionally, the antimicrobial activity of DSF-reinforced composites has never been studied. The incorporation of cinnamon essential oil (CEO) in biocomposite as secure antimicrobials is expected to be non-harmful for food product and human application. To bridge the gap in the research on active packaging and antimicrobial activity, this study on PLA/DSF biocomposites incorporated with epoxidized palm oil (EPO) and cinnamon essential oil (CEO) was performed. This paper reported the effects of cinnamaldehyde on the physical and functional properties of DSF-reinforced PLA biocomposite films.

EXPERIMENTAL

Materials

The PLA used was bought from NatureWorks (Wenzhou, China). The PLA grade was 4024D with a density of 1.24 g/cm^3 and a glass transition temperature of 55 °C to 58 °C. The durian skin waste was collected from a local market. The durian skin was processed into DSF (Manshor *et al.* 2014). Chloroform was used as a solvent, which was supplied by Merck (Selangor, Malaysia). The EPO was obtained from Advanced Oleochemical Technology Division (AOTD) of the Malaysian Palm Oil Board (MPOB; Bangi, Malaysia). The CEO was procured from Best Formula Industries (Kuala Lumpur, Malaysia).

Preparation of the Biocomposites

The biocomposite films were prepared *via* a solvent casting method. Before proceeding, all sample were dried in vacuum oven at 40 ºC for 24 h. The PLA and DSF were dried prior to the biocomposite preparation. In this study, the DSF and EPO were fixed at 3 wt.% and 5 wt.%, respectively. This was based on the results of Anuar *et al.* (2016), who studied the effects of the fiber and plasticizer contents on the tensile properties of PLA biocomposites. The ratio of chloroform to composite was 5:1. Chloroform was added to dissolve the composite for the solvent casting process. The mixture was then stirred at 250 rpm with a magnetic stirrer until the compound no longer aggregated. Then, 5 wt.% EPO was added into the PLA solution for a plasticizing effect. The CEO was added into the plasticized PLA/DSF biocomposite from 0 wt.% to 5 wt.%. Details of the prepared samples are listed in Table 1. After that, the biocomposite solution was cast into a flat surface mold. The biocomposite solution was left at room temperature for 24 h in fume closest, which has been reported to be enough time for complete evaporation of the chloroform to occur (Grigale *et al*. 2010).

Table 1. Food Type and Food Simulants (Simoneau 2009)

Food type	Food simulant	Abbreviation
Aqueous foods (pH > 4.5)	Distilled water	Simulant A
Acidic foods (pH ≤ 4.5)	Acetic acid 3% in water	Simulant B
Alcoholic foods	Ethanol 10% in water (v/v) Ethanol X% adjust % for foods with >10%	Simulant C
Fatty foods	Rectified olive oil or other fatty food simulants such as Iso-octane and 95% Ethanol	Simulant D
Milk products	Ethanol 50% in water (v/v)	

Water Absorption Test

The water absorption test determines the most important property of biodegradable plastics. The purpose of this test was to study the effects of immersion in distilled water on the PLA biocomposites. This test was performed according to ASTM D570-098 (2010). The dimensions of each sample were 20 mm × 20 mm. For each composition, five samples were immersed in distilled water for 2 months. After this, the samples were removed from the distilled water, blotted with tissue paper to remove excess water on the sample surface,

and then weighed. The weight of the samples was recorded every day for the first 14 d, and then once a week until the values equalized, which was after approximately 30 d. The water absorption (%) was calculated from the difference in the weight at a certain time and the initial dry weight of the sample (Eq. 1),

$$\textit{Water absorption}\ (\%) = \frac{W_i - W_o}{W_o} \times 100\% \quad (1)$$

where W_i is the weight of the sample (g) at time i (d) and W_o is the initial weight of the sample (g).

Soil Burial Test

The soil burial degradation test was done to examine the biodegradability of the PLA biocomposites. Four samples of each composition were tested. This test was performed according to ASTM D5988-12 (2012). The dried film samples were cut to the dimensions 50 mm × 50 mm and the initial mass of each sample was weighed with a balance scale. Then, four samples of each composition were buried in separate holes in the ground. They were buried in soil to a depth of 5 cm from the surface. The test was performed and the composites were left buried for 50 d and longer until the biocomposites disappeared. During the test, the biocomposites were removed from the soil at specified time periods and rinsed with water, which was followed by soft blotting with tissue paper to remove excess water. Then, the samples were weighed. Fig. 1 shows the biocomposites after 14 d. The weight losses of the samples were calculated after 50 d according to Eq. 2,

$$\textit{Weight loss}\ (\%) = (M_0 - M_i) \times 100\% \quad (2)$$

where M_i is the mass of the sample at 50 d (g) and M_0 is the initial mass of the sample (g).

The samples were then observed with scanning electron microscopy (SEM; JEOL JSM-5600, JEOL Inc., Tokyo, Japan).

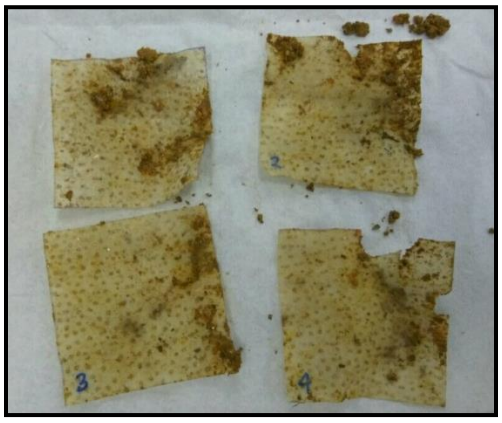

Fig. 1. Soil burial test after 14 d

Dart Drop Impact Test

The dart drop impact test was done to determine the energy needed to cause the films to fail under the specified conditions. According to ASTM D1709-09 (2009), the energy was expressed as the weight of a missile falling from 0.66 m. The dimensions of the biocomposite specimens were 20 mm × 20 mm. For each composition, 20 biocomposite

specimens were tested. The model of the dart impact machine used was PARAM FDI-01 falling dart impact tester (Instron Inc., Texas, USA).

For the dart drop impact test, the method used to analyse the results was the staircase method. If a test sample passed the test, the drop weight was increased by one unit. If a test sample failed, the drop weight was decreased by one unit. The results from these impacts were used to calculate the impact failure weight, which was when 50% of the test sample failed under impact. The impact failure weight was calculated using Eq. 3,

$$W_F = W_0 - [\Delta W\,(A/N - 1/2)] \quad (3)$$

where W_F is the impact failure weight or impact strength (g), W_0 is the lowest missile weight (g) when i is 0, ΔW is the missile weight increment used (g), A is the sum of N_i (samples used), and N is the number of failures.

Tear Test

The tear resistance (or tear strength) is a measure of how well a material can withstand the effects of tearing. This test is important for plastic films because it determines the expected life span. A force in grams was required to propagate a tear across a film or sheeting specimen and was measured using a precisely calibrated pendulum device. Using gravity, a pendulum swung through an arc, tearing the specimen with help from a pre-cut slit. The specimen was held on one side by the pendulum stand and on the other side by a stationary member.

This test method is of value in ranking the relative tear resistance of various plastic films and thin sheeting with comparable thicknesses. This test method should be used for specification acceptance testing only after it has been demonstrated that the data for the material is acceptably reproducible. The average tearing force was determined with the standard ASTM D1938-08 (2008) on an 800-gram-force (gf), Instron Ceast ED 300 electronic tear tester (Elmendorf, West Berlin, NJ, USA) with a 0 to 100 scale and calculated using Eq. 4,

$$Average\ tearing\ force\ (gf) = \frac{(8\ x\ average\ scale\ reading)}{n} \quad (4)$$

where n is the number of specimens used.

Migration Test

Migration is the transfer of chemical substances from food contact materials (food packaging in this case) into the food itself. There are two types of migration: overall migration and specific migration. Overall migration is defined as the sum of all of the substances that may migrate from the food contact material to the food, while specific migration is applied to an individual substance. Analytical techniques are used to identify the presence of these substances in the food. The migration limit set by the Commission Regulation (EU) No. 10/2011 is 10 mg/dm^2 (Traistaru *et al.* 2013). All of the migrating substances should not exceed this limit or the plastic cannot be used for food packaging. The method for determining the overall migration is based on BS EN 1186-1 (2002), which is the overall migration standard for materials in contact with foodstuffs.

It was assumed that the mechanisms governing the migration in this case was diffusion, where the movement of the molecular structure flows from higher concentrations to lower concentrations. Adsorption can also lead to migration. Migration is affected by several factors, such as the nature of the food, the type, time, and temperature of the contact,

the nature of the packaging material, the characteristics of the migrants, and the amount of migrant contained in the packaging materials (Arvanitoyannis and Kotsanopoulos 2014).

Food simulants were used for the migration test in place of food because of the complex chemical and physical structure of food. The simulants were either in liquid or solid form. A variety of food simulants have been used. However, Commission Regulation (EU) No. 10/2011 proved by Malaysia Food Packaging Institute has provided examples of food simulants that should be used, which are shown in Table 2.

Table 2. Food Types and Food Simulants

Food Type	Food Simulant	Abbreviation
Aqueous foods (pH > 4.5)	Distilled water	Simulant A
Acidic foods (pH ≤ 4.5)	3% acetic acid in water	Simulant B
Alcoholic foods	10% (v/) ethanol in water X% ethanol, adjusted for foods with > 10%	Simulant C
Milk products	50% (v/v) ethanol in water	Simulant D1
Fatty foods	Rectified olive oil or other fatty food simulants, such as iso-octane and 95% ethanol	Simulant D2

Simoneau (2009)

RESULTS AND DISCUSSION

Water Absorption of the PLA Biocomposites

The water absorption property is an important factor for food packaging because of the important role of water in deteriorative reactions. The major deteriorative reactions are targets for preservation. The percentage of water absorption by the PLA biocomposites was calculated using Eq. 1 and is shown in Fig. 2. Water affected the biocomposite according to its elemental composition. During this test, the water absorption percentage slowly increased over time. The experiment was conducted until a saturation trend was obtained, which was after 30 d. Figure 2 shows that the initial water absorption rate was fast, but it slowed down before reaching a steady state of absorption. The steady state value is the equalized content, which is considered to be the maximum amount of water that can be absorbed by a biocomposite film.

Figure 2 shows that the PLA/DSF biocomposite absorbed 5.9% water, which was the highest compared with that of the other compositions. The tendency of the composites to attract water molecules was high because of the lignocellulosic structures that make up the DSF. By reinforcing the hydrophobic polymer with hydrophilic fibers, swelling within the matrix occurred (Kabir *et al.* 2012). This was followed by a weakening of the bond between the fibers and matrix, which led to poor mechanical properties of the composites. Chemical treatment, such as with alkali and silane, can be applied to the fiber surface so that the hydrophilic hydroxyl bonds can be removed (Wang *et al.* 2007). The presence of EPO lessened the uptake of water, as can be seen in Fig. 2, because EPO contains triglycerides oil, which is insoluble in water (Güner *et al.* 2006). This makes EPO hydrophobic. The effects of the CEO on the water absorption of the PLA is also shown in Fig. 2. The biocomposite containing CEO had an approximately 3.8% water absorption. Cinnamon essential oil is a complex mixture that is highly hydrophobic, and so it increased the hydrophobicity of the film matrix (Grumezescu 2016). Figure 2 shows that the presence

of CEO was effective at protecting the PLA biocomposite and helped to prevent water absorption into the biocomposite.

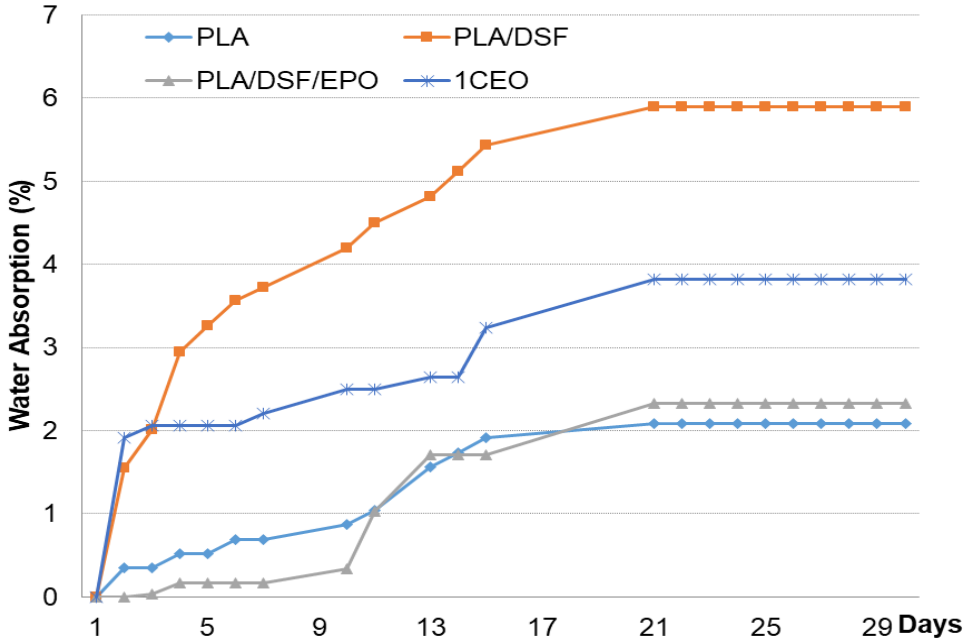

Fig. 2. Water absorption of the PLA/DSF/EPO/CEO biocomposites

Weight Loss of the PLA Biocomposites

The soil burial degradation test was conducted by measuring the weight loss and visually inspecting the physical appearance of the biocomposite films over time. After 50 d of soil burial, the sample was morphologically observed under SEM. The physical appearances of the PLA biocomposite films after buried in the soil for 60 d are shown in Fig. 3. The weight loss percentage was determined with Eq. 2. A reduction in the weight because of the degradation of the biocomposite included the absorption of moisture from the soil and emergence of micro-organisms. In the end, this process led to a reduction in the mechanical properties (Amer and Saeed 2015).

Table 3. Weight Loss of the PLA Biocomposites

Sample	Weight (g) (± 0.0001 g)		Weight Loss (%)
	Initial	Final	
PLA	0.3990	0.2540	14.5
PLA/DSF	0.4653	0.1352	33.1
PLA/DSF/EPO	0.4430	0.2990	14.4
PLA/DSF/EPO/CEO	0.4112	0.2344	17.7

Table 3 shows that the PLA/DSF sample had the highest weight loss at 33.1%. This could have been because the natural fibers are highly compatible with the environment and made the sample degrade faster in the soil. The presence of EPO strengthened the interaction between the PLA and DSF. This agreed with the tensile results of the PLA/EPO

blends, which revealed that the flexibility of the PLA biocomposite is improved with the addition of EPO as a plasticizer (Ali *et al.* 2016).

Table 3 also shows the effects of the CEO on the degradability of the PLA/DSF biocomposites. The 5 wt.% CEO content weakened the biocomposite and made it degrade faster than the other additives. This might have been because of the existence of pores, which reduced the barrier properties of the films (Souza *et al.* 2013). Hence, as the films were buried in the soil, they tended to degrade faster because of weak bonds in the biocomposite. Additionally, some additives from the biocomposite samples might have migrated into the soil and contributed to the degradation process (Lardjane and Belhaneche-Bensemra 2009).

Physical Appearance

The changes to the color, shape, and size of the samples during a soil burial degradation test can be seen in Fig. 3. Figure 3 shows the physical appearances of the PLA biocomposite films 14 d, 28 d, 42 d, 50 d, and 60 d after being buried in soil. All of the biocomposites were obviously changed after 60 d of burial (Fig. 3). The shapes of the samples were similar to the original shapes after 14 d buried in the soil, but their colors were slightly paler when compared with the original colors.

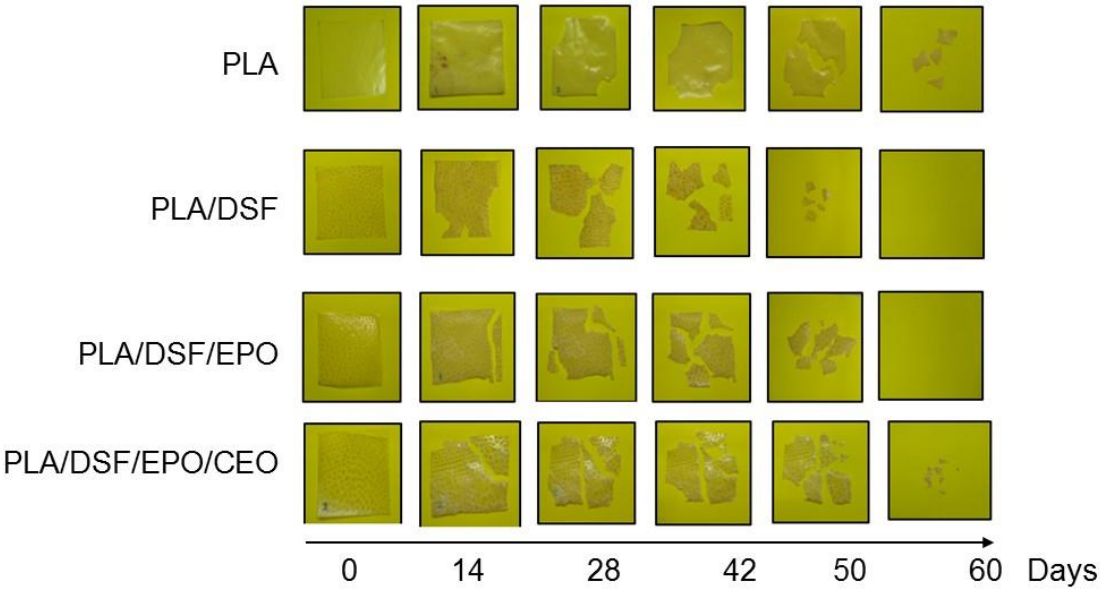

Fig. 3. Physical appearance of the PLA biocomposite films after being buried in soil

It was noted that there were black and yellow stains on the film surfaces. This might have been because of microbial growth or morphological alterations. All of the biocomposites had broken into smaller pieces. Similar observations were also seen for the PLA/DSF/EPO biocomposite in Fig. 3. However, the PLA/DSF film was faster to degrade than the PLA/DSF/EPO film. Both of the samples had completely disappeared by day 60. The natural fibers consisted of cellulose, which promoted microbial growth and appeared as discoloration on the materials because of the organic nature of the compound (Amer and Saeed 2015). Microorganisms can change the sample pH, and thus changed the color of the samples (Phetwarotai *et al.* 2013). The CEO also affected the PLA/DSF biocomposite. Fig. 3 shows that 5 wt.% CEO easily split the biocomposite into smaller pieces. It has been

reported that a higher CEO content tended to increase the porosity on the sample surface (Souza *et al.* 2013).

Figs. 4 and 5 show the surface morphology of the PLA/DSF/EPO biocomposite without CEO and the PLA/DSF/EPO biocomposite with 1 wt.% CEO before and after 50 d of the soil burial degradation test. The influence of the CEO during degradation of the biocomposite was clearly apparent. Fig. 5a shows that the biocomposite with CEO contained more pores compared with the biocomposite without CEO (Fig. 4a). It was also observed that before the soil burial test, the biocomposites had a smooth surface. In contrast, Figs. 4b and 5b show that the films buried in the soil were physically rougher and had an abundance of small holes on the surface.

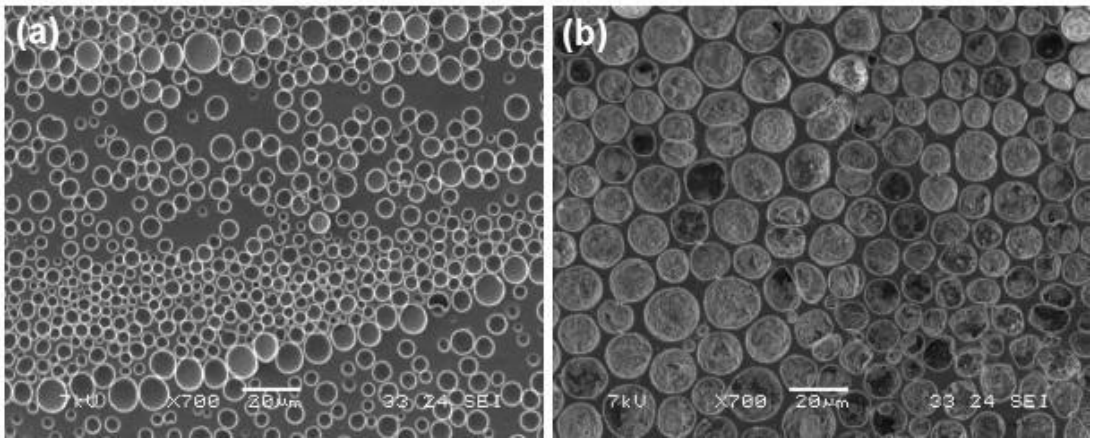

Fig. 4. Surface morphology of the PLA/DSF/EPO (a) before and (b) after 50 d of the soil burial test

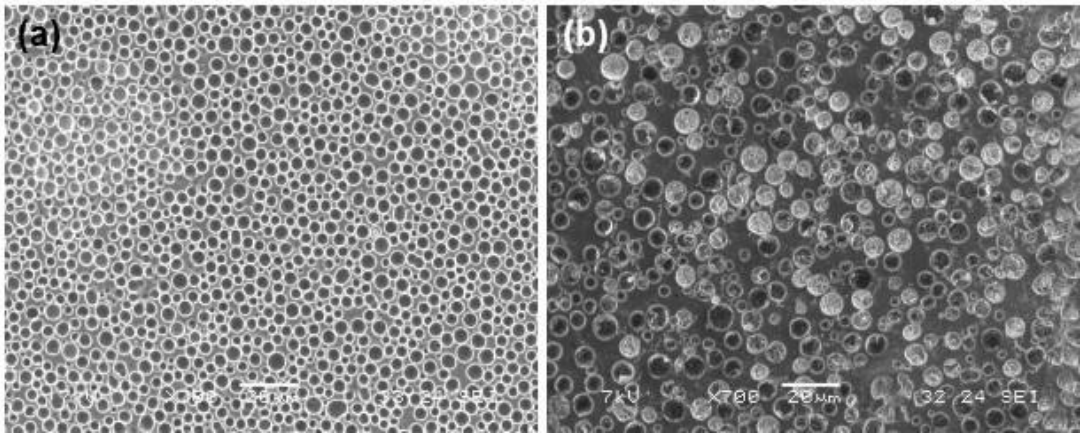

Fig. 5. Surface morphology of the PLA/DSF/EPO with 1 wt.% CEO (a) before and (b) after 50 d of the soil burial degradation test

Dart Drop Impact Test

The main purpose of the dart drop impact test is to assess the durability and strength of plastic films and other related products. The test determined the energy that was required to cause the plastic film to fail under the specified conditions. The energy was expressed in terms of the weight (mass) of a missile free falling from 0.66 m that resulted in a 50% failure of the sample.

Table 4. Dart Drop Impact Failure Weight of the PLA Biocomposite Films

Sample	Impact Failure Weight (g)
PLA	62.5
PLA/DSF	32.5
PLA/DSF/EPO	33.5
PLA/DSF/EPO/CEO	28.5

Table 4 shows the results of the impact failure weight of the PLA biocomposite films. As was mentioned previously, the addition of EPO improved the flexibility of the biocomposite. This was because of the strong bond between the PLA and EPO, which acted as a plasticizer and increased the flexibility of the PLA. The pure PLA biocomposite also had a higher value for its impact failure weight (65.5 g of missile). This was because of the existence of the matrix. The 100% PLA biocomposite had zero fibers present. The same dart drop impact test method was conducted on a pure PP film by Kissin (2008). The value for the PP film (47 g of missile) was lower than that of the unfilled PLA film. Therefore, it was concluded that PLA is tougher than PP because a higher missile weight is required to break PLA films. However, with DSF, the impact strength decreased. Higher volumes of fibers within the PLA matrix resulted in fiber agglomeration or fiber clustering. This reduced the interfacial interaction between the fiber and matrix (Singh *et al*. 2008). Similarly, the PLA/DSF biocomposite required a smaller missile weight to break the films, which was shown in the dart impact test. However, the strength was slightly increased by 1 g with the addition of EPO to the biocomposite.

It was also observed in Table 4 that the sample without CEO had a higher impact weight failure compared with that of the biocomposite with 1 wt.% CEO. This indicated that the biocomposites without CEO are tougher, which meant that they required a higher missile weight to break the films. However, as was mentioned previously, an increase in the porosity might have occurred and resulted in a multiplicity of void spaces and relatively low degree of physical contact between the microstructures as CEO was incorporated into the PLA/DSF biocomposite.

Tear Test

Table 5 shows the tear resistance for the PLA and biocomposites. The tear resistance unit is gram-force and it was calculated using Eq. 3. The biocomposite with PLA, DSF, EPO, and 1 wt.% CEO had the highest tear resistance, which was 217 gf. This could have been because of the presence of CEO, which acted as a plasticizer. The function of the plasticizer was to increase the ductility and flexibility of the PLA biocomposite film. It was also shown that the addition of DSF may have increased the tear strength of the PLA biocomposite films. Table 5 shows that the presence of DSF enhanced the strength of the biocomposites when compared with that of the unfilled PLA. The tear resistance was highly amplified with the addition of EPO and CEO. This showed that the incorporation of DSF, EPO, and CEO complemented each other *via* improvement of the ductility and flexibility of the biocomposites. A previous study on a PP/HDPE/EVA blend with 4 wt.% PLA indicated that the tear strength value was 17.25 gf (Monika *et al*. 2014). Thus, the addition of CEO to the biocomposites increased the tear resistance of the films.

Table 5. Tear Resistance of the PLA Biocomposite Films

Composition	Tear Resistance (gf)
PLA	32.8
PLA/DSF	36.0
PLA/DSF/EPO	44.8
PLA/DSF/EPO/CEO	217

Migration Test

The migration tests studied the DSF-reinforced PLA biocomposites with CEO and CEO in contact with simulants A, B, C, and D1 at 40 °C for 10 d and simulant D2 at 40 °C for 30 min. The test was conducted using the PLA/DSF/EPO/CEO film because, based on a previous study, this biocomposite had the highest tensile properties (Anuar *et al.* 2016). The total amounts of migrants that migrated from the film are given in Table 6. The results showed that the overall migration values from the biocomposite into simulants A (10% ethanol), C (20% ethanol), D1 (50% ethanol), and D2 (iso-octane) were 4.30 mg/dm^2, 2.66 mg/dm^2, 5.95 mg/dm^2, and 0.25 mg/dm^2, respectively. These food simulants were used at certain concentrations as a replacement for actual foodstuffs because of the difficulty of conducting the test with food. Overall, the migration studies showed that the migration rate was very low, far below the allowed limit of 10 mg/dm^2 set by the EU Regulation 10/2011.

The overall migration value for simulant B (3% acetic acid) was 6.96 mg/dm^2, which was the highest compared with that of the other simulants. Simulant B represented an acidic food. This result indicated that acidic food can most easily diffuse through the biocomposite films into the food compared with the other food types. However, the value still did not exceed the allowed limit set by EU Regulation 10/2011. According to a previous study by Şengül and Dilsiz (2014), the migration rates for PLA were 1.14 mg/dm^2, 2.39 mg/dm^2, and 1.84 mg/dm^2 for aqueous, fatty, and acidic foods, respectively. The migrants from the PLA may have included lactic acid, lactoyllactic acid, other small oligomers, and lactide. It was expected that the lactic acid and its derivatives would migrate from the PLA into the food simulants. This can be understood based on the presence of CEO and its effect on the material which increased the rate of migration. The presence of EPO might have also affected the migration rate. This could have been because of other migrants from EPO, which is an epoxidized derivative of a mixture of ester and glycerol with various saturated and unsaturated fatty acids. The plasticizer may have migrated from the plastic into the fatty food (Bhunia *et al.* 2013). Unreacted monomers and oligomers may have also migrated from the plastic into the simulants. The results given in Table 6 suggested that the composites are suitable to be used as food packaging for all types of food because the results did not surpass the set migration standards when tested with aqueous, alcoholic, acidic, fatty, and milk food product types.

Table 6. Migration Study of the PLA Biocomposite Films

Food Simulant	Overall Migration (mg/dm^2)
10% ethanol (Simulant A)	4.30
20% ethanol (Simulant C)	2.66
50% ethanol (Simulant D1)	5.95
3% acetic acid (Simulant B)	6.96
Iso-octane (Simulant D2)	0.25

CONCLUSIONS

1. Polylactic acid biocomposite films that included durian skin fibers (DSF), epoxidized palm oil (EPO), and cinnamon essential oil (CEO) were successfully produced *via* a solvent casting process. Water absorption and biodegradable tests were performed to determine the physical properties of the biocomposite films.
2. The presence of CEO in the biocomposites slowed the rate of water absorption and reduced the weight loss when buried in soil. The impact failure weight of the biocomposite also decreased with the addition of CEO.
3. The migration test suggested that PLA biocomposites developed with DSF, EPO, and CEO are suitable for use as food packaging for all types of food.

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