Characterization of Ripe Empty Bunch Fruit (EFB) Oil on The Properties of Starch-PLA Bio-based Plastic

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***Abstract*— In recent decades, biodegradable and renewable polymers have intensively attracted attention due to their huge influence on cutting the human pollution. Blending of Poly (lactic acid) PLA with starch will increase the biodegradability of the polymers. In this study, ripe empty fruit bunch (EFB) oil was used as a compatibilizer to improve the thermoplastic starch (TPS) /poly lactic acid (PLA) blend. A different amount of ripe EFB oil (0, 2.5, 5.0, 7.5, 10g) and poly lactic acid (PLA) (0.05g and 0.1g) were used to produce the bio-based plastic with gelatinization process and dried at 40°C for 48 hours. The produced bio-based plastic was named as Starch-PLA-B and characterized using Fourier Transform Infrared Spectroscopy (FTIR), Universal Tensile Testing Machine, Water Solubility, Water Vapor Permeability (WVP) and Biodegradation test. The FTIR analysis shows the O-H bonding, C-H bonding and N-H bonding decreases as the composition of ripe EFB oil incorporated with the Starch-PLA-B matrix increases. The Starch-PLA-B have a tensile strength, Young's Modulus and Percentage of elongation in the range of 1.8-7.95 MPa, 27.6-79.7Mpa and 19.8-52.7%, respectively. The solubility of the Starch-PLA-B is in the range of 6.25-20.83% when incorporated with ripe EFB oil. Water Vapor Permeability of the Starch-PLA-B is between 0.82×10^{-11} g/m.s.Pa and 2.00×10^{-11} g/m.s.Pa. The blend of TPS/PLA has proven to have a characteristic of bio-plastic as it is biodegradable when buried in soil.**

Keywords*— *Biodegradable, Thermoplastic, Poly (lactic) Acid, Polymer, Gelatinization, Bio-based Plastic, Empty Fruit Bunch (EFB) Oil

I. INTRODUCTION

In recent decades, biodegradable and renewable polymers have intensively attracted attention due to their huge influence on cutting the human pollution. A polymer was a building blocks of small molecules into a macro-molecules through polymerization process. The polymer can be categorized as synthetic and natural polymer.

Synthetic polymer was derived from petroleum oil and were made by a scientist and engineer using chemical methods while natural polymers was obtained from plants and animals which were naturally formed. Poly lactic acid (PLA) was one of the most significant examples of this category which was grown from natural resources such as corn, starch and bread.

PLA was a thermoplastic polyester that has a comparable property to those of synthetic polymers from its stiffness, tensile strength and gas permeability. However, PLA has low degradation rate, relatively expensive, and sustain a high inherent brittleness that limits its use [1].

Blending of PLA with other natural polymers that deliver a high degradation rate was extremely recommended to overcome the low degradation rate of PLA [2]. Starch was one of the best prospects to increase the degradation of PLA as to its low cost, abundance and availability from different botanical sources.

Bio-based polymers were sustainable polymers synthetically made of renewable resources such as biomass rather than the typical fossil fuel resources such as petroleum oil and natural gas, in preference based on biological and biochemical processes. They were characterized by the nature of carbon neutral or carbon offset in which the atmospheric carbon dioxide concentration does not increase even after their incineration [3].

Most of these polymers which were natural, synthetic or bio-based were used in the manufacturing of plastics. The properties of the polymers used will affect the properties of the plastics produced. Nowadays, there were many types of plastic being manufactured and there was a lot of new types of plastic that was still under ongoing research, study and under development process.

To date, plastic was one of the most important material in the world for the various manufacturing industries from textile, packaging, parts of equipment and devices, insulating cable and wire, marine equipment, medical application and etc. Generally, all the devices, equipment and material around us consist of plastics or fully manufactured using plastics.

Bio-based plastic was more biodegradable compared to plastic derived from petroleum. A plastic derived from petroleum takes a very long time to degrade and it was causing a serious pollution to the environment which have become a major concern to the environment [4]. Significant quantities of plastic have gathered in the natural environment and in landfills. Wasted plastic also contaminates a wide range of natural terrestrial, freshwater and marine habitats [5]. Therefore, a bio-based plastics which have a high biodegradability rate compared to petroleum derived plastics was highly sought in the market.

Another alternative to raw materials in manufacturing plastics. To avoid a rapid depletion of petroleum in the world, a bio-based polymer was used for the manufacturing of plastics. The oil that was used as a raw material, as well as the oil required for energy, consumes between six to eight percent of the total world oil production. Although this is a small percentage, the amount of petroleum used to make plastic does contribute to the depletion of fossil fuels [5].

Bio-based plastic was a field of study that was rapidly emerging and have a high probability in substituted for petroleum derived plastic. Due to its high demand in market and limited information, various research and study was conducted to improve the properties of the bio-based plastic. Currently, the bio-plastics market was coming out of its infancy and capturing the plastics market at a growth rate of 30% annually. Many researchers were working to derive new compounds from biological resources either by industrial biotechnology or by chemical methods [6].

Thermoplastic starch and PLA were hydrophilic and hydrophobic respectively, which will result in a poor adhesion between the polymer matrix [7].

This research was motivated by current studies for the development of biodegradable polymers. A new type of compatibilizer which was the ripe EFB oil was used to produce a bio-based plastic. To evaluate the efficiency of the ripe EFB oil as a compatibilizer, a different blend of the TPS/PLA containing different amount of the ripe EFB oil was prepared via gelatinization process. The influence of the ripe EFB oil on the bio-based plastic on chemical structure, mechanical, solubility, permeability and biodegradability properties of the compounds were studied and discussed in detail.

II. METHODOLOGY

Potato starch (Bob's Red Mill) was purchased at a local market in Shah Alam, Selangor, Malaysia. The ripe empty fruit bunch (EFB) oil was bought from the local supermarket. Glycerol of analytical grade with 85% purity (Merck) and distilled water was obtained from the chemical storage and laboratory at the Faculty of Chemical Engineering, UiTM Shah Alam. The Poly (lactic Acid) beads or PLA beads with Nature Works brands was purchased online from the Supplier.

A. Preparation of Poly (lactic Acid) PLA

The Poly (lactic acid) or PLA was obtained in the formed of beads. The PLA was extruded using a HAAKE™ Rheomex OS Single Screw Extruder at a temperature of 180°C and 6 RPM. The extruded PLA was in the form of a ribbon. The PLA ribbon was crushed into a small granule particle using a compact crusher.

B. Preparation of Bio-based plastic

The bio-plastic was successfully obtained by the gelatinization an aqueous dispersion of 1 wt. % of potato starch powder. Glycerol was added into the aqueous dispersion at a fixed amount of 2 wt. %. Then, the mixture was heated at 80 °C for 15 min [8] under continuous stirring at 800 rpm [8]. A modification was made from this method by using a fixed amount of 8-g potato starch, 100-ml distilled water, 2-ml glycerol [9] and addition of ripe EFB oil. Then, the heated temperature was modified to be set at 120°C until the mixture reaches 63°C before glycerol, ripe EFB oil and the PLA was added [10]. Then, the mixture was left to homogenized and gelatinized for another 15 minutes with a temperature of 80°C and a continuous stirring at 1200 RPM [10]. The produced bio-based plastic were obtained through drying in a vacuum oven at 40 °C for 48-hours [8]. This bio-based plastic was named Starch-PLA-B. The different composition for the Starch-PLA-B was shown in Table 2.1 below.

Table 2. 1 Composition of Ripe EFB Oil and PLA for the Starch-PLA-B.

Starch-PLA-B	Ripe EFB Oil	PLA
TPS_0	0	None
$TPS_{2.5}$	2.5	
TPS_5	5.0	
$TPS_{7.5}$	7.5	
TPS_{10}	10.0	
$TPS_0/PLA_{0.05}$	0	0.05
$TPS_{2.5}/PLA_{0.05}$	2.5	
$TPS_5/PLA_{0.05}$	5.0	
$TPS_{7.5}/PLA_{0.05}$	7.5	
$TPS_{10}PLA_{0.05}$	10.0	
$TPS_0/PLA_{0.1}$	0	0.1
$TPS_{2.5}/PLA_{0.1}$	2.5	
$TPS_5/PLA_{0.1}$	5.0	
$TPS_{7.5}/PLA_{0.1}$	7.5	
$TPS_{10}PLA_{0.1}$	10.0	

C. Fourier-Transform Infrared Spectroscopy (FTIR)

The FTIR spectra of the bio-plastic samples were analyzed using the PERKIN ELMER SPECTRUM ONE FT-IR Spectrometer. The analyses were performed after the samples were dried and left in the desiccator overnight [3]. The spectra were collected over a range of frequencies from 4000 cm-1 to 500 cm-1 [3], with a spectral resolution of 1 cm-1 [3].

D. Tensile Strength

This method was done to fulfill objective number two of this research which were to study the properties of the bio-based plastic produced. The tensile behavior of the bio-based plastics was determined following the ASTM D882 standard method by using a Universal Testing Machine (Tinius Olsen H25 KT).

A handheld digital micrometer was used to measure the bio-based plastic thickness at five random positions around the bio-based plastic. Then, the bio-based plastic strips of 25-mm wide and50-mm long were mounted in the tensile grips which have a distance of 30-mm between the bio-based plastic and grips that stretched at 50 mm/min until breaking. The elastic modulus (EM), tensile strength at break (TS) and percentage of elongation at break (E) were obtained from the stress-strain curves [11].

E. Solubility

Specimens were conditioned for three days in a desiccator containing silica gel at 0% RH [12]. Then, a sample of 25-mm wide and 25 mm-length was dried in an oven at 105 °C for 12 hours. Then, the sample was weighed, immersed in distilled water for 48 hours at 25 °C [12], and dried again at 105 °C for 12 hours [12]. The weight of the specimen after drying was used to calculate the percentage of mass solubilized in water (SCW).

$$\text{Percentage of Solubility (\%)} = W_b\text{-}W_a /W_b \times 100\% \qquad \text{[Eqn. 1]}$$

Where W_b was the weight of the sample before submersion and W_a was weight of sample after submersion.

F. Water Vapor Permeability

The water vapor permeability (WVP) of the bio-based plastics was determined according to the ASTME 96-95 gravimetric method. Round bio-based plastic samples of 80mm diameter of each formulation were placed in glass bottles containing 15-g silica gel at 25°C and at 100% RH [11] gradient, which was created with a distilled water. The glass bottle was weighed periodically using a weighing balance (±0. 01 g). The measurements were taken for 1 week at 25°C [11]. The WVP rate was calculated from the equation in [13] as shown below.

$$WVP= C\ x/A\Delta P \qquad \text{[Eqn. 2]}$$

Where WVP was in g/m.s.Pa. x was the film thickness in (m), A was the area of the exposed samples in (m2), ΔP was the differential pressure across the samples which was at 1 atm, and C was the slope of the weight gain versus time [13].

G. Biodegradability Test

This method is done to fulfil objective number two of this research project. The biodegradation trial will be performed under natural environmental conditions, in a bed of normal soil at the yard behind the laboratory in faculty of chemical engineering. The reading for temperature, moisture and pH of the soil is taken. Then, the sample was buried at a depth of 5-cm from the surface [29]. The trial was set for 2 weeks and the sample was collected after 2 weeks' time for further observation.

III. RESULTS AND DISCUSSION

A. Preparation of the bio-based plastic (Starch-PLA-B)

In this research, potato starch has been used over corn and cassava starch. In the early stage of the research, three types of starch have been chosen which were the potato starch, cassava starch and corn starch. The criteria chosen to select which starch will be used in the research were the time required for gelatinization to occur at 120°C. From these three starches, potato starch was chosen as it has the fastest gelatinization rate, which were at an hour. Followed by cassava starch at 2 hours' time and corn starch at 3 hours' time.

The bio-based plastic produced (Starch-PLA-B) with ripe EFB oil have a layer of oil on its surfaces. The presence of oil occurs because oil was a hydrophobic substance which was immiscible in water. The excess amount of oil that was not homogenized through the gelatinization process during the heating has resulted in the oily surfaces of the Starch-PLA-B. Even though PLA helps to smoothen the surface area of the Starch-PLA-B, the presence of PLA did not do much in lessening the oily surfaces of the Starch-PLA-B.

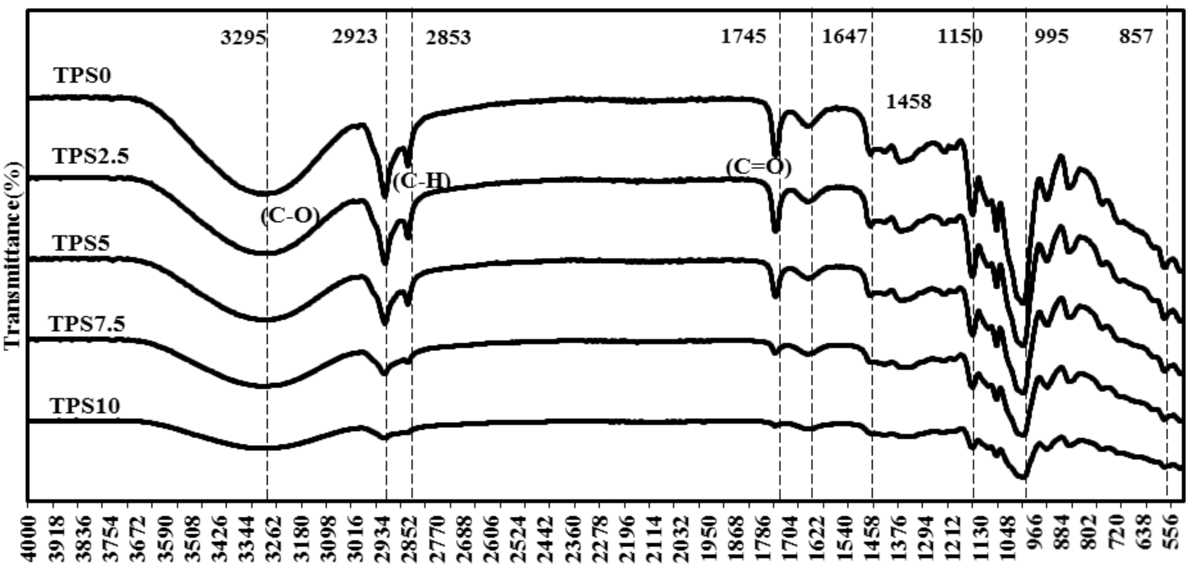
The Starch-PLA-B with the presence of PLA has a smooth surfaces compared with the Starch-PLA-B without the PLA. However, the Starch-PLA-B show the presence of the PLA granules on its surfaces as PLA have a very high melting temperature at 180°C. The PLA granules will not blend or dissolve in the starch solution as the temperature used during the gelatinization process was much lower compared to its melting temperature. At the same time, PLA was also hydrophobic and immiscible in water [1].

B. Characterization of the Starch-PLA-B.

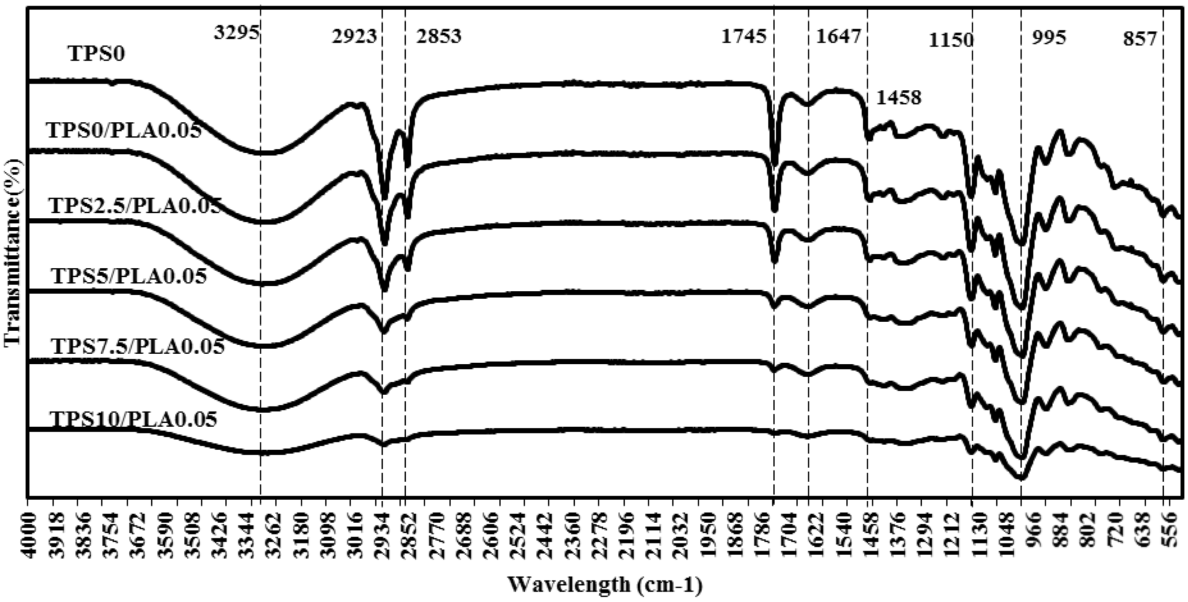
The FTIR spectra analysis shows a result for two regions which were the regions with absorbance at low wavelength numbers between 500-1700cm-1 and the second region at high wavelength numbers between 2300-3600cm-1 [14]

The molecular bonds and functional group interaction within the Starch-PLA-B can be analyzed based on Figure 3.1. The high intensity of peak shown in the graph represents more retention of the functional group.

From Figure 3.1 (a), (b) and (c) the spectral graph peak become more subtle as the amount of the ripe EFB oil increases. The wavelength between 3310-3270cm^{-1} depicted the O-H stretching, C-H stretching [15] and N-H stretching [16]. Then, a band of 2925cm^{-1} correspond to the elongation of C-H bonds [10] where in the analysis was between a wavelength of 2930-2920cm^{-1}. CH2 stretching modes (alkyl stretching modes, (R-CH2) [17]happens at wavelength of 2850-2855cm^{-1}. Between the wavelength of 1740-1750cm^{-1} [15] and 1645-1650cm^{-1} [7], a C=O stretching was depicted. A band of 1450-1460cm^{-1} stretching of aromatic rings like a glass fibre reinforced polyester [7]. At a wavelength of 1330-1380cm^{-}1, 1230-1240$cm^{-1,}$ and 1150-1160cm^{-1} the C-O-C stretching vibration, C-O-C asymmetrical and symmetrical valence vibration and C-O-C ester asymmetric stretching [15] occurred. The spectral analysis in the range of 1100-1120cm-1 wavelength depicted a combination of stretching of C-O and bending of CH [18]. Stretching of C-O bond [19]was associated at wavelength of 1080-1000cm-1. Bands of wavelength 920-860cm^{-1} depicted the stretching of C-C single bond [20]. At a wavelength of 720-721cm^{-1}, CH2 was rocking [16] was attributed580cm^{-1} the spectral peak were attributed to the absorption peak for SiO2 and Si-O vibration.



(a)



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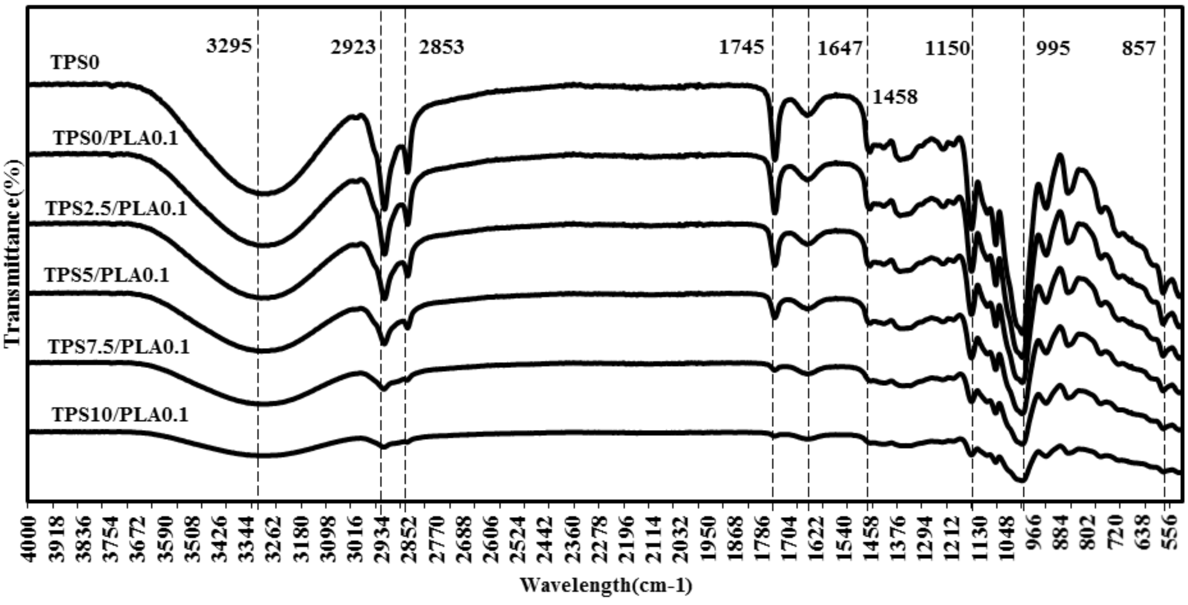


(c)

Figure 3. 1: FTIR Spectra Graph (a) TPS (B) TPS/PLA0.05 (c) TPS/PLA0.1

C. Mechanical Properties

The tensile properties of the Starch-PLA-B were depicted in Table 3.1. Based on previous studies, Thermoplastic Starch (TPS) and all other blends have a much lower tensile strength comparable to that of pure PLA [1] and the tensile strength of TPS/PLA blends with equal ratio of oil and glycerol have the largest value of maximum stress [21]. At the same time, a high amount of ripe EFB oil makes the Starch-PLA-B more thickly than sample with low amount of ripe EFB oil. From this research, ripe EFB oil makes the Starch-PLA-B decrease in tensile strength and increase its thickness.

Table 3.1: Mechanical Properties of the Starch-PLA-B.

Starch-PLA-B	Thickness (mm)	Young's Modulus (MPa)	Tensile Strength (MPa)	Elongation at Break (%)
TPS_0	0.3662	79.7	7.35	52.7
$TPS_{2.5}$	0.5042	59.7	4.44	38.7
TPS_5	0.5968	27.6	2.90	40.7
$TPS_{7.5}$	0.6824	30.3	2.11	37.7
TPS_{10}	0.9562	63.3	2.37	19.8
$TPS_0/PLA_{0.05}$	0.4014	31.1	5.22	38.0
$TPS_{2.5}/PLA_{0.05}$	0.5566	32.3	3.31	36.0
$TPS_5/PLA_{0.05}$	0.6488	57.4	2.59	36.3
$TPS_{7.5}/PLA_{0.05}$	0.7908	44.5	1.80	31.2
$TPS_{10}PLA_{0.05}$	0.7798	62.3	2.12	39.3
$TPS_0/PLA_{0.1}$	0.3782	58.9	7.93	41.3
$TPS_{2.5}/PLA_{0.1}$	0.4786	47.8	7.29	33.7
$TPS_5/PLA_{0.1}$	0.6006	36.1	5.38	40.0
$TPS_{7.5}/PLA_{0.1}$	0.7394	29.4	3.04	35.7
$TPS_{10}PLA_{0.1}$	0.8428	35.2	2.20	28.4

Figure 3.4 depicted the changes of tensile strength along with

increasing amounts of ripe EFB oil. Tensile strength depicted the resistance of material to break under tension. The tensile strength of the Starch-PLA-B decreases as the amount of ripe EFB oil in the formulation increases. From Figure 3.2, Starch-PLA-B with 0.1g PLA shows a much higher tensile strength compare to Starch-PLA-B with 0.05g PLA and 0g PLA. However, when TPS was added with PLA, the tensile strength show changes as TPS/PLA$_{0.05}$ have a much lower tensile strength compared with TPS [19]. Then, when the amount of PLA increased, the tensile strength of the TPS/PLA$_{0.1}$ improved. This shows there were interaction between TPS and PLA when ripe EFB oil added as a compatibilizer. Both starch and PLA have opposites mechanical properties which lead to the Starch-PLA-B to have mechanical characteristic that is slightly better than thermoplastic starch and PLA bio-plastic only [22].

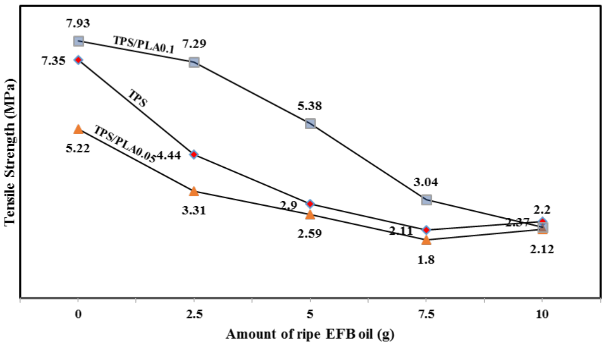


Figure 3.2: Tensile Strength

Then, increment of ripe EFB oil shows the increase in the Young's Modulus which increase the elasticity of the Starch-PLA-B. Young's Modulus is the measure of the stiffness of a plastic or polymer where the higher the value of the Young's Modulus, The stiffer the plastic and the less likely for the polymer to deforms. Based on Figure 3.2, TPS$_0$ and TPS$_{10}$ with different amount of PLA have the highest value of Young's Modulus.

The result of the Young's Modulus has a same trend as tensile strength where it shows that TPS have better Young's Modulus value which were 79.7 MPa compared with TPS/PLA$_{0.05}$ blend with 31.1 MPa. Then it shows an improvement on the Starch-PLA-B properties when the amount of PLA was increased which shows the value of TPS/PLA$_{0.1}$ was better than TPS/PLA$_{0.05}$ which were 59.8 MPa. The lower the value of the Young's Modulus, the more easily the Starch-PLA-B to deforms which prove the Starch-PLA-B was more elastic and less stiff.

Young's Modulus were directly proportional with the percentage of elongation. Thus, the percentage of elongation at break will increase as the value of Young's Modulus decreases. The trend of the percentage of elongation was similar to the tensile strength result to some extend when compatibilizer (ripe EFB oil) is added. The increment of the ripe EFB oil make the Starch-PLA-B have a decrease in percentage of elongation. The decrease in the percentage of elongation may be due to ripe EFB oil where the phase separation acts as defect sites that reduces the elongation at break [21]. Percentage of elongation study the ductility of a material or compound. According to previous study, a higher ductility can be obtained if the mechanical properties of the Starch-PLA-B were improved [22].

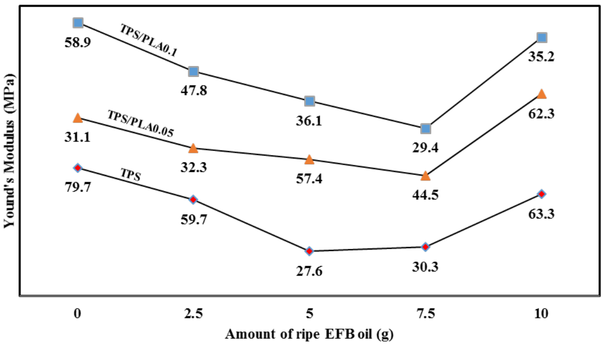


Figure 3.3: Young's Modulus

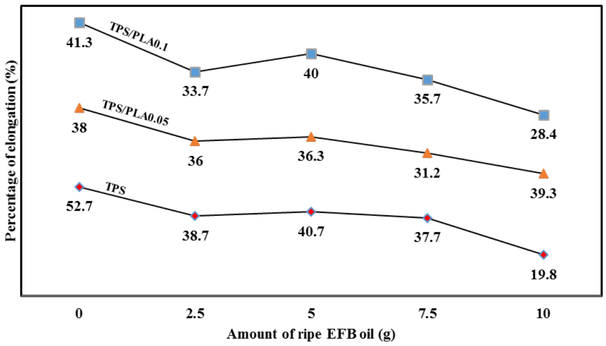


Figure 3.4: Percentage of Elongation

D. *Solubility*

The produced Starch-PLA-B have a percentage of solubility in the range of 6.25-20.83%. Table 3.2 depicted the percentage of solubility in a distilled water under room temperature for the different composition of Starch-PLA-B. Solubility was the ability of the compound to dissolve in water or solvent.

Table 3.2: Percentage of Solubility

Starch-PLA-B	After drying Process		Percentage of Solubility (%)
	Weight of sample before submersion, W$_b$, (g)	Weight of sample after submersion, W$_a$, (g)	
TPS$_0$	0.56	0.49	12.5
TPS$_{2.5}$	0.40	0.36	10.0
TPS$_5$	0.46	0.40	13.04
TPS$_{7.5}$	0.32	0.36	6.25
TPS$_{10}$	0.33	0.27	18.18
TPS$_0$/PLA$_{0.05}$	0.52	0.45	13.46
TPS$_{2.5}$/PLA$_{0.05}$	0.52	0.44	15.38
TPS$_5$/PLA$_{0.05}$	0.41	0.36	12.20
TPS$_{7.5}$/PLA$_{0.05}$	0.42	0.35	16.67
TPS$_{10}$PLA$_{0.05}$	0.24	0.19	20.83
TPS$_0$/PLA$_{0.1}$	0.53	0.45	15.09
TPS$_{2.5}$/PLA$_{0.1}$	0.46	0.39	15.21
TPS$_5$/PLA$_{0.1}$	0.38	0.34	10.52
TPS$_{7.5}$/PLA$_{0.1}$	0.37	0.30	18.91
TPS$_{10}$PLA$_{0.1}$	0.30	0.25	16.67

The Starch-PLA-B with the lowest percentage of solubility was the TPS$_{7.5}$ sample followed by TPS$_{2.5}$ and TPS/PLA$_{0.1}$ sample with 6.25, 10.0 and 10.52% of solubility. From Figure 3.5, the solubility of the Starch-PLA-B increases as the amount of ripe EFB oil was 10g. Ripe EFB oil and PLA were a hydrophobic compound which should make the bio-based plastic less soluble. However, the interaction between starch, PLA, glycerol and ripe EFB oil have weakened the C-H bonds, which repel the water molecules within the polymer matrix. Thus, increased the solubility of the samples.

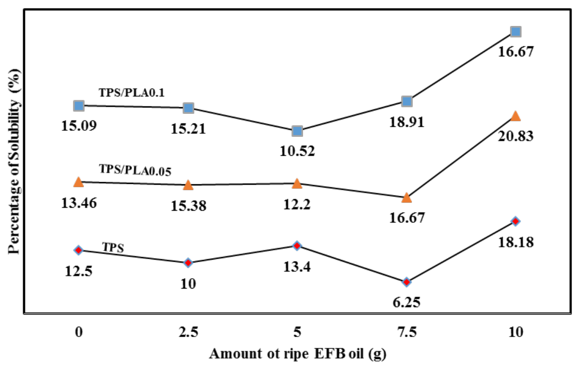


Figure 3.5: Effect of ripe EFB oil on Percentage of Solubility

At the same time, Figure 3.6 shows how the presence of PLA makes the Starch-PLA-B less soluble. From the graph, there were only a small difference between the solubility of Starch-PLA-B with 0.05g and 0.1 g of PLA. However, a significant change was observed between the Starch-PLA-B without the addition of PLA. The increase in the Starch-PLA-B solubility is due to the introduction of a hydrophobic ester bond in starch chains from the ripe EFB oil and PLA which increase the interfacial compatibility that led to Starch-PLA-B water resistance [22].

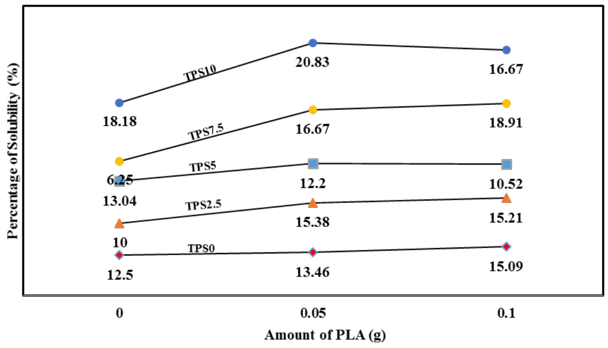


Figure 3.6: Effect of PLA on Percentage of Solubility

E. Water Vapor Permeability (WVP)

The WVP rate of the Starch-PLA-B was in the range of 0.82×10^{-11} g/m.s.Pa to 2.00×10^{-11} g/m.s.Pa. The thickness of the Starch-PLA-B affects the WVP rate as depicted in Table 3.3 and Figure 3.7. WVP is the material's ability to allow water pass through it under the action of pressure between its two opposite's faces. Table 3.3 depicted the WVP rate under room temperature and 1 atm pressure.

Table 3.3: Water Vapor Permeability Rate

Types of Sample	Thickness (mm)	WVP Rate $\times10^{11}$ (g/m.s.Pa)
TPS$_0$	0.3662	0.82
TPS$_{2.5}$	0.5042	1.13
TPS$_5$	0.5968	1.17
TPS$_{7.5}$	0.6824	1.33
TPS$_{10}$	0.9562	2.00
TPS$_0$/PLA$_{0.05}$	0.4014	0.90
TPS$_{2.5}$/PLA$_{0.05}$	0.5566	1.24
TPS$_5$/PLA$_{0.05}$	0.6488	1.27
TPS$_{7.5}$/PLA$_{0.05}$	0.7908	1.66
TPS$_{10}$PLA$_{0.05}$	0.7798	1.42
TPS$_0$/PLA$_{0.1}$	0.3782	0.84
TPS$_{2.5}$/PLA$_{0.1}$	0.4786	1.00
TPS$_5$/PLA$_{0.1}$	0.6006	1.26
TPS$_{7.5}$/PLA$_{0.1}$	0.7394	1.45
TPS$_{10}$PLA$_{0.1}$	0.8428	1.65

PLA and Ripe EFB oil were a hydrophobic compound which should make the Starch-PLA-B less permeable. However, Figure 3.7 shows an increase of the WVP rate as the amount of ripe EFB oil increases. As mentioned before, the thickness of the Starch-PLA-B affects the WVP rate where Starch-PLA-B with a thin layer have a much lower WVP rate compared to Starch-PLA-B with a thicker layer.

According to a research, an increase of WVP can occur when plasticizers or compatibilizer was added to the polymer matrix which in this research refer to the Starch-PLA-B [13]. The Starch-PLA-B matrix that incorporated with high amount of ripe EFB oil have caused the attractive forces between the Starch-PLA-B chains to decrease which resulted in free volumes and segmental motions within the Starch-PLA-B matrix. These phenomenal makes water molecules easily diffused through the layer of the Starch-PLA-B which resulted in the high WVP rate [13].

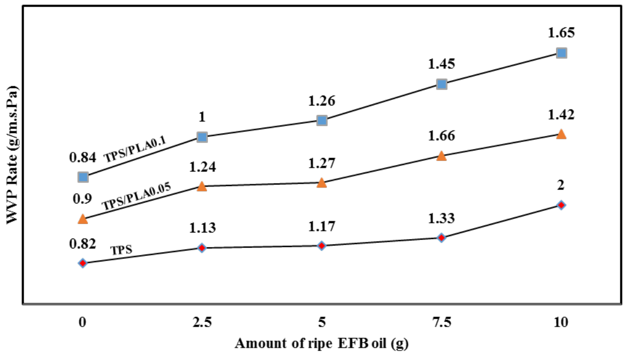


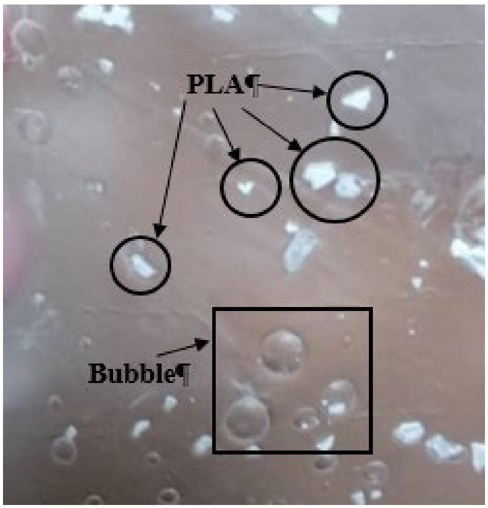
Figure 3.7: Effect of ripe EFB oil on the WVP rate.

F. Biodegradability

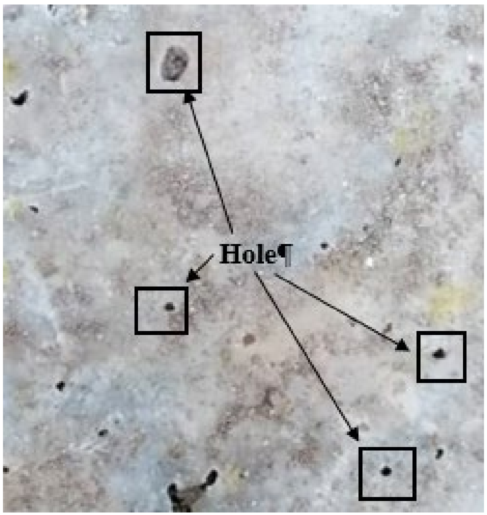
Biodegradability of the Starch-PLA-B in soil was due to the diversity of microorganism presence [4]. All the Starch-PLA-B was dug out after 2 weeks and only TPS$_0$/PLA$_{0.05}$ remain after 2 weeks. The condition of the TPS$_0$/PLA$_{0.05}$ before and after 2 weeks was shown in Figure 3.8.

From this test, it was observed that the Starch-PLA-B with the presence of oil was more biodegradable as there was no trace of the Starch-PLA-B after 2 weeks. Starch-PLA-B with 0.05g of PLA has a low biodegradability rate compared to the Starch-PLA-B containing ripe EFB oil. It was observable that the surface and texture of the Starch-PLA-B shows a major changes from Figure 3.8.

Figure 3.8(a) shows the presence of PLA and bubble on the Starch-PLA-B. At the same time, from Figure 3.8(a), the Starch-PLA-B has an almost clear plastic surfaces. However, in Figure 3.8(b), it was observable that there were many hole presence on the Starch-PLA-B surfaces. The hole were both caused by the bubble and the PLA granule. At the same time, it was clearly observable that the Starch-PLA-B has become more cloudy and murky due to the exposure to the soil.



(a)



(b)

Figure 3.8: Pictures of TPS0/PLA$_{0.05}$ (a) Before 2 weeks (b) After 2 weeks

IV. CONCLUSION

In this research, different composition of ripe EFB oil and PLA were blended into the potato starch plasticization and gelatinization process. The Starch-PLA-B compounded in this research have improved the solubility and biodegradability of the Starch-PLA-B blends. The mechanical properties of the Starch-PLA-B have a bit of improvement as the sample produced with 2.5g, 5.0g and 7.5g of ripe EFB oil shows a good ability to deform when incorporated with 0.05g and 0.1 g of PLA. The amount of the ripe EFB oil affect the thickness, solubility and water vapor permeability of the Starch-PLA-B. The high amount of ripe EFB oil increases the thickness of the Starch-PLA-B and causes the water vapor permeability to increase. This result can be supported through the FTIR analysis where the interaction of functional groups within the Starch-PLA-B gradually weakens as the amount of ripe EFB oil increases. The ripe EFB oil aided in the biodegradation of the bio-based plastic as the Starch-PLA-B successfully degraded in the span of 2 weeks' time.

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REFERENCES

[1] M. Akrami, I. Ghasemi, H. Azizi, M. Karrabi, and M. Seyedabadi, "A new approach in compatibilization of the poly(lactic acid)/thermoplastic starch (PLA/TPS) blends," *Carbohydr Polym,* vol. 144, pp. 254-62, Jun 25 2016.10.1016/j.carbpol.2016.02.035

[2] C. Medina Jaramillo, T. J. Gutierrez, S. Goyanes, C. Bernal, and L. Fama, "Biodegradability and plasticizing effect of yerba mate extract on cassava starch edible films," *Carbohydr Polym,* vol. 151, pp. 150-159, Oct 20 2016.10.1016/j.carbpol.2016.05.025

[3] K. Masutani and Y. Kimura, "Biobased Polymers," in *Encyclopedia of Polymeric Nanomaterials*, S. Kobayashi and K. Müllen, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, 2015, pp. 1-7.

[4] S. M. Emadian, T. T. Onay, and B. Demirel, "Biodegradation of bioplastics in natural environments," *Waste Manag,* vol. 59, pp. 526-536, Jan 2017.10.1016/j.wasman.2016.10.006

[5] R. V. Gadhave, A. Das, P. A. Mahanwar, and P. T. Gadekar, "Starch Based Bio-Plastics: The Future of Sustainable Packaging," *Open Journal of Polymer Chemistry,* vol. 08, no. 02, pp. 21-33, 2018.10.4236/ojpchem.2018.82003

[6] M. M. Reddy, S. Vivekanandhan, M. Misra, S. K. Bhatia, and A. K. Mohanty, "Biobased plastics and bionanocomposites: Current status and future opportunities," *Progress in Polymer Science,* vol. 38, no. 10-11, pp. 1653-1689, 2013.10.1016/j.progpolymsci.2013.05.006

[7] N. S. Yatigala, D. S. Bajwa, and S. G. Bajwa, "Compatibilization improves physico-mechanical properties of biodegradable biobased polymer composites," *Composites Part A: Applied Science and Manufacturing,* vol. 107, pp. 315-325, 2018.10.1016/j.compositesa.2018.01.011

[8] V. Sessini, M. P. Arrieta, J. M. Kenny, and L. Peponi, "Processing of edible films based on nanoreinforced gelatinized starch," *Polymer Degradation and Stability,* vol. 132, pp. 157-168, 2016.10.1016/j.polymdegradstab.2016.02.026

[9] L. M. Brito, P. J. O. Sebastião, and M. I. Bruno Tavares, "NMR relaxometry evaluation of nanostructured starch-PLA blends," *Polymer Testing,* vol. 45, pp. 161-167, 2015.10.1016/j.polymertesting.2015.06.011

[10] B. F. Bergel, S. Dias Osorio, L. M. da Luz, and R. M. C. Santana, "Effects of hydrophobized starches on thermoplastic starch foams made from potato starch," *Carbohydr Polym,* vol. 200, pp. 106-114, Nov 15 2018.10.1016/j.carbpol.2018.07.047

[11] R. Requena, M. Vargas, and A. Chiralt, "Obtaining antimicrobial bilayer starch and polyester-blend films with carvacrol," *Food Hydrocolloids,* vol. 83, pp. 118-133, 2018.10.1016/j.foodhyd.2018.04.045

[12] M. O. Reis, J. B. Olivato, A. P. Bilck, J. Zanela, M. V. E. Grossmann, and F. Yamashita, "Biodegradable trays of thermoplastic starch/poly (lactic acid) coated with beeswax," *Industrial Crops and Products,* vol. 112, pp. 481-487, 2018.10.1016/j.indcrop.2017.12.045

[13] K. Nazan Turhan and F. Şahbaz, "Water vapor permeability, tensile properties and solubility of methylcellulose-based edible films," *Journal of Food Engineering,* vol. 61, no. 3, pp. 459-466, 2004.10.1016/s0260-8774(03)00155-9

[14] N. Nordin, S. H. Othman, R. Kadir Basha, and S. Abdul Rashid, "Mechanical and thermal properties of starch films reinforced with microcellulose fibres," *Food Research,* vol. 2, no. 6, pp. 555-563, 2018.10.26656/fr.2017.2(6).110

[15] D. K. Wang *et al.*, "FT-IR characterization and hydrolysis of PLA-PEG-PLA based copolyester hydrogels with short PLA segments and a cytocompatibility study," *Journal of Polymer Science Part A: Polymer Chemistry,* vol. 51, no. 24, pp. 5163-5176, 2013.10.1002/pola.26930

[16] K. Forfang, B. Zimmermann, G. Kosa, A. Kohler, and V. Shapaval, "FTIR Spectroscopy for Evaluation and Monitoring of Lipid Extraction Efficiency for Oleaginous Fungi," *PLoS One,* vol. 12, no. 1, p. e0170611, 2017.10.1371/journal.pone.0170611

[17] H. S. Mansur, R. L. Oréfice, and A. A. P. Mansur, "Characterization of poly(vinyl alcohol)/poly(ethylene glycol) hydrogels and PVA-derived hybrids by small-angle X-ray scattering and FTIR spectroscopy," *Polymer,* vol. 45, no. 21, pp. 7193-7202, 2004.10.1016/j.polymer.2004.08.036

[18] D. Saviello, L. Toniolo, S. Goidanich, and F. Casadio, "Non-invasive identification of plastic materials in museum collections with portable FTIR reflectance spectroscopy: Reference database and practical applications," *Microchemical Journal,* vol. 124, pp. 868-877, 2016.10.1016/j.microc.2015.07.016

[19] J. F. Mendes *et al.*, "Biodegradable polymer blends based on corn starch and thermoplastic chitosan processed by extrusion," *Carbohydr Polym,* vol. 137, pp. 452-458, Feb 10 2016.10.1016/j.carbpol.2015.10.093

[20] R. Arjmandi, A. Hassan, M. M. Haafiz, Z. Zakaria, and I. Inuwa, "Characterization of polylactic acid/microcrystalline cellulose/montmorillonite hybrid composites," *Malaysian J. Anal. Sci,* vol. 18, pp. 642-650, 2014.

[21] V. Volpe, G. De Feo, I. De Marco, and R. Pantani, "Use of sunflower seed fried oil as an ecofriendly plasticizer for starch and application of this thermoplastic starch as a filler for PLA," *Industrial Crops and Products,* vol. 122, pp. 545-552, 2018.10.1016/j.indcrop.2018.06.014

[22] J. Muller, C. Gonzalez-Martinez, and A. Chiralt, "Combination of Poly(lactic) Acid and Starch for Biodegradable Food Packaging," *Materials (Basel),* vol. 10, no. 8, Aug 15 2017.10.3390/ma10080952