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Biodegradation Kinetic Study of Cassava & Tannia Starch-Based Bioplastics as Green Material in Various Media

Marcelinus Christwardana[1]*, Ismojo[2], Sidik Marsudi[1]

[1] Department of Chemical Engineering, Institut Teknologi Indonesia, Jl. Raya Puspiptek Serpong, South Tangerang, Indonesia 15314
[2] Department of Automotive Mechanical Engineering, Institut Teknologi Indonesia, Jl. Raya Puspiptek Serpong, South Tangerang, Indonesia 15314

*Corresponding author email: mchristwardana@gmail.com

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ABSTRACT. The rate of biodegradation of cassava – tannia starch bioplastic in various media was evaluated. Bioplastic degradation profile for a period of 4 weeks was seen following the Hills Equation where the speed of bioplastic biodegradation in sand media had higher yields than farm soil and compost media with the value up to 98.84 %. This is also proven by measuring the rate of degradation reaction using a first order reaction rate, where the value of the constant rate of reaction from bioplastics in sand is a little bit higher compared to farm soil and compost media (0.77647, 0.67133, and 0.15779 week^{-1}, respectively). According to SEM pictures, there were numerous bacteria (either aerobic or anaerobic) and fungal species on the bioplastic surface, which have a role in the biodegradability of the polymer in bioplastics. The FTIR spectra of bioplastic biodegradation showed a decrease in the peak at 3400 - 3200 cm^{-1}, and loss of the peak was present in the control at 2900 cm^{-1} which showed a breakdown of the polymer chain in the bioplastic especially in the O-H and C-H bonds, respectively. It can be concluded that farm soil and sand are the most optimal media in the bioplastic biodegradation process, while compost has potential but its maturity must be considered.

Keywords: biodegradability, biodegradation rate, biopolymer, Hill curves, starch-based bioplastic.

INTRODUCTION

Plastic is the most widely used polymer in our daily lives. The durable nature of commercial plastics makes it an ideal material to be applied to carriers or packages purposes. In 2015, petroleum-based plastic production exceeded 300 million tons (Mekonnen, Mussone, Khalil, & Bressler, 2013).

Plastic becomes an integral part of the waste stream considering its usability is not continuous or disposable. After not being used, the plastic is thrown into the environment. Human behavior that does not respect the environment makes this plastic waste accumulate in the environmental ecosystem (Tokiwa, Calabia, Ugwu, & Aiba, 2009; Pathak, Sneha, & Mathew, 2014; Jain, & Tiwari, 2015). The accumulation is due to its resistance to the degradation process carried out by microbes. What is worse, million tons of plastic waste is produced annually around the world, and some of them are discharged into the ocean, places that are not supposed to be plastic waste receptacles.

Efforts are made by the world community in the field of biodegradable considering that several issues have been thrown in the middle of the world, including the depletion of fossil sources, development of renewable natural resources that are more sustainable, more global environmental regulations, and the introduction of composting technology for processing waste biologically. The excessive production of petroleum-based plastics also motivates communities to look for sustainable alternative materials from renewable resources. New interests are beginning to emerge, including the development of biomass-based packaging or carriers that can be recycled or can be decomposed. One example is bioplastics, which have the ability to degrade biologically because they are made from biopolymers (Pathak et al., 2014).

Polymer biodegradation consists of three crucial steps, namely, biodeterioration, biofragmentation, and assimilation. In the biodeterioration process, there is a modification of the mechanical, chemical, and physical properties of the polymer caused by the growth of microorganisms on the polymer surface. Then the process of change from the polymer into oligomeric and monomeric forms by the activity of microorganisms, and this process is called biofragmentation. After that, the assimilation process occurs where the carbon source from the plastic is converted into CO_2, water, and biomass (Lucas et al., 2008). Chemical structure, polymer chains, crystallinity, and complexity of polymer formulas are intrinsic factors that influence bioplastic biodegradation in nature whereas the media pH content, temperature, humidity, and oxygen of the environment are influential extrinsic factors (Massardier-Nageotte, Pestre, Cruard-Pradet, & Bayard, 2006; Kale et al., 2007b).

Many researchers have previously investigated the biodegradability of bioplastics in different environmental media, such as soil, compost, seawater, and water from other aquatic environments. Soil and compost are often used in such studies by considering high microbial diversity (Anstey, Muniyasamy, Reddy, Misra, & Mohanty, 2014; Tabasi, & Ajji, 2015; Adhikari et al., 2016; Sarasa, Gracia, & Javierre, 2009). The activity of these microorganisms is related to the composting process in which organic material is converted to CO_2, and materials are like soil, called humus (Kale et al., 2007b).

In addition to research related to biodegradation media, research on bioplastic composition is carried out to improve biodegradability in various environmental variations. Starch-based ingredients are widely used as the main ingredient in making bioplastics. Starches consisting of amylose and amylopectin have excellent film-forming properties in terms of chemical stability and are also edible because of their biocompatible properties (Duarah, Singh, Mandal, & Karak, 2016; Shi et al., 2010). The use of starch as a biopolymer in the manufacture of bioplastics is based on its availability, which is abundant in nature, low in price, and easily degraded biologically. In addition to bioplastics, starch can also be used in biomedical applications, such as tissue scaffolding (Gomes, Ribeiro, Malafaya, Reis, & Cunha, 2001) or implants (Araújo, Cunha, & Mota, 2004) because it has relatively good biocompatibility properties. Although it has several advantages, starch also has several limitations, including high soluble temperature, poor solubility of large amylopectin branched macromolecules, and moisture sensitivity (Arvanitoyannis, Kalichevsky, Blanshard, & Psomiadou, 1994; Thiré, Simão, & Andrade, 2003). This is also indeed very influential in its nature of biodegradation in the environment.

Some studies reported cassava starch commonly used as the main ingredient in making bioplastics or thin films, and this shows cassava starch is very popular compared to other starches (Teixeira et al., 2012; Paes, Yakimets, & Mitchell, 2008; Arrieta, Gañán, Márquez, & Zuluaga, 2011). Bioplastics made from cassava starch have relatively better characteristics compared to starch from other sources. However, this is still being debated where parallelly cassava is also used as a prime food, especially in Southeast Asian countries, including Indonesia. This also applies to corn, yams, and potatoes. This requires starch from other plants, which are not a source of staple crops, to be used as cassava substitutes for bioplastic manufacturing. Tannia (*Xanthosoma* sp.) is a potential plant that can be used as a bioplastic base material. Tannia is a relative of taro (*Colocasia* sp), which has an amylose content of about 30-35% (Pérez, Schultz, & de Delahaye, 2005). Until now, Tannia rarely been utilized as a bioplastic raw material, as well as for food. This is different from taro, which has been reported several times as raw material from both bioplastics and foods (Pramodrao, & Riar, 2014; Asria, 2016; Hasan et al., 2019).

In this study, tannia starch was used as a substitute for cassava starch as a bioplastic material. Glycerol used as a plasticizer and acetic acid used as a starch hydrolysis agent. Bioplastic biodegradation would be rewarded by burying bioplastics in three different media; sand, farm soil, and compost. Biodegradation in this type of bioplastic has never been studied, thus making this an academic novelty in this work. The rate of biodegradation is measured and studied based on the Hill equation, while the kinetics constant of biodegradation is measured based on the rate of first-order reactions. SEM and FTIR images of bioplastics after and before the biodegradation process would be examined.

EXPERIMENTAL SECTION

Materials

Cassava starch was obtained from Dwilab Mandiri (Bandung, Indonesia) with the amount of starch and ash were 85.49% and 0.16%, respectively, of the dry mass. While the pH was 6.1 with a moisture content of 12.35%. Tannia flour was provided by KWT Bina Mandiri (Banten, Indonesia), which would be further processed to get the starch. Glycerol was purchased from Merck (New Jersey, USA), while acetic acid (Technical Grade, 98%) was purchased from ROFA Laboratory Center (Bandung, Indonesia).

Tannia Starch Preparation

The starch extraction method used in this study was adapted from previous studies (Ashri et al. 2014; Sharlina et al., 2017). Tannia flour was mixed with distilled water in a volume ratio (1: 3) and blended for 5 minutes using a blender. Then, the water mixed with flour was filtered using a double cheesecloth. The retentate was then put into the blender and mixed with distilled water again to blend like the previous process. The blending and filtering process were carried out three times. The total filtrate was transferred to a container to be allowed to stand overnight for a starch deposit at the bottom of the container. The supernatant was removed, and the precipitate was dried at room temperature. Finally, the dried starch was then ground using a grinder and then stored in a polyethylene bag.

Table 1. Composition of cassava – tannia starch bioplastic

Composition	100-0	95-5	90-10	80-20	50-50	5-95
Cassava starch (g)	9.50	9.03	8.55	7.60	4.75	0.47
Tannia starch (g)	0.00	0.47	0.95	1.90	4.75	9.03
Glycerol (mL)	5	5	5	5	5	5
Acetic acid 5% v/v (mL)	5	5	5	5	5	5
Distilled water (mL)	60	60	60	60	60	60

Cassava-Tannia Starch-Based Bioplastic Preparation

Bioplastic forming solutions were prepared by mixing cassava starch and tannia starch (following to composition in **Table 1**) into 60 mL of distilled water, then stirred for 60 seconds (Christwardana, Ismojo, & Marsudi, 2021). Next, 5 mL of glycerol was added to the mixture, followed by stirring for 60 seconds. The 5% v/v acetic acid as much as 5 mL was then fed into the mixed solution and stirred again for 60 seconds. Later, this process was followed by heating and stirring at 60 °C for 10 minutes. After that, heating was stopped, and stirring was continued for 60 seconds to reduce the amount of foam produced. The solution was then spread to the glass mold surface which was then dried at 30 °C for seven days using an oven.

Biodegradation Process

Biodegradability of starch-based bioplastic was evaluated by measuring bioplastic weight loss during incubation at 30 °C for 4 weeks. Biodegradation of bioplastic samples was carried out on different media, including farm soil, sand, and compost, all of which were simulated on a laboratory scale. Farm soil was taken from orchid plantations located in the Institut Teknologi Indonesia complex, Serpong. While sand was purchased from building material stores, and compost was obtained from the local plant market in Serpong, Indonesia.

Weight loss curves are modeled using the Hill model (Calmon, Silvestre, Bellon-Maurel, Roger, & Feuilloley, 1999) to confirm and to measure the behavior of starch-based bioplastic degradation in various degradation media, following equation (**1**):

$$y = y_{max} \cdot \frac{t^n}{k^n + t^n} \quad (1)$$

where y is the percentage of weight loss [%] at time t [week]. While y_{max} [%] represents the percentage of degradation at infinite time, *k* [week] represents half-life, and n is the radius of the sigmoidal function curve.

Scanning Electron Microscopy

The surface morphology of the starch-based bioplastic was examined using a Field-Emission Scanning Electron Microscope (FE-SEM) FEI Inspect F50 (Oregon, USA). The sample was prepared by attaching on a two-sided conductive adhesive tape and coated with carbon to make it more conductive. The images obtained from the SEM analysis before and after the degradation process were comparatively analyzed.

Fourier-Transmittance Infra-Red (FTIR) Spectroscopy

The functional groups in bioplastics before and after the biodegradation process were analyzed using the FTIR method with a wavelength of 600 - 3700 cm^{-1}. For this reason, FTIR Shimadzu FTIR-8400s (Kyoto, Japan) was used for analysis purposes with reference to the ASTM method E1252-13 (ASTM, 2013)

RESULTS AND DISCUSSION

Biodegradation Process

Laboratory-scale screening tests of bioplastic degradation in several media such as farm soils, sand, and compost have been carried out. This test provides an overview of the degradation time of a bioplastic based on a mixture of cassava starch and tannia starch. The biodegradation results can be seen in **Figure 1**, and the Hill parameters of all samples are presented in **Table 2**. There are three noticeable things that can be discussed interestingly. First, **Figure 1** confirms that all bioplastic samples biologically degraded, characterized by an increase in % weight loss. After being buried for four weeks, some bioplastic samples almost disappeared. This is following an experiment conducted by Domenek, Feuilloley, Gratraud, Morel, & Guilbert (2004), who tested biodegradation of gluten-based bioplastics, where bioplastics have completely disappeared after being buried for 50 days in farm soil. Second, the highest increase in % weight loss occurred when bioplastics were buried in farm soil (**Figure 1a**), then those buried in sand (**Figure 1b**), and the lowest was when bioplastics were buried in compost (**Figure 1c**). It is astonishing that compost, which contains many decomposing microorganisms, degraded bioplastics slower than sand. On farm soil, many microbes were found. For instance, *Clostridium sp,* which could produce H_2 gas by reducing starch-based bioplastic (Yoshida, Ye, Liu, Li, & Katayama, 2013) and fungus *Aspergillus sp* which reducing polysaccharides using their enzymes (Li et al., 2015). Means, compost used in this experiment was not mature enough so that the amount of microorganism lesser than in farm soil. Sand particles have larger structure than farm soil or compost and only have a little bit of microorganism content. So, when bioplastics were buried, air could enter through the sand pores to further assist the bioplastic degradation process. Pores in farm soil are also larger than compost, made the degradation process took place faster. Whereas compost has smaller pores and made air could not reach the inside part, even though compost has abundant mineral and microorganism content. Third, the replacement of cassava starch by tannia starch in bioplastic composition caused bioplastics to degrade faster. According to Emadian, Onay, & Demirel, (2013), the rate of degradation is also affected by the size of the bioplastic constituents apart from the number of microorganisms and conditions in the media. Bioplastics last longer degraded if they have large particle sizes. Tannia starch was suspected did not bind strongly to cassava starch, so bioplastics that contain lots of tannia starch in the composition were degraded faster.

Some bacteria and fungi are capable of degrading polymers. Most studies focus on the role of bacteria in the degradation process, thus almost forgetting the role of fungi (Kim and Rhee, 2003). Fungi place bioplastics as a food source, so hypha filaments attach to bioplastics and form a colony. The enzymes produced from these filaments form a thin biofilm in which the substances formed on the biofilm will decompose the bioplastic matrix (Accinelli, & Abbas, 2011). To provide more specific data on the integration of bioplastics, the Hill model is used. The Hill model is used to calculate the kinetic parameter values of various biodegradable polymers to date (Calmon, et al., 1999). The percentage of maximum weight loss and at four weeks, half-life, curvature, and coefficient determination are given in **Table 2**. Values calculated from Y_{max} have values higher than those observed for four weeks. This is since the Hill model calculates degradation indefinitely, while the experimental value is obtained for only four weeks. There are some significant differences observed in the addition of Tannia starch as substitute material, such as a smaller half-life (*k*) obtained when there is an increase in the level of tannia starch in the mixture composition. This applies to all media, both sand, agricultural land, and compost. However, the amount of half-life time varies. Bioplastics buried in soil media have a half-life of between 1.42 and 3.61 weeks. While bioplastics buried in sand media have a half-life of 1.67 to 3.48 weeks, and those buried in compost had values between 6.35 to 57.94 weeks. From these results, it is confirmed that the rate of bioplastic degradation by compost was the longest, while the sand and farm soil media were more or less similar. Curvature (n) of bioplastic degradation in all media had a value above 1, which means it has an increased affinity for degradation. While some samples in compost media had a curvature value below 1, which means they have a decreased affinity.

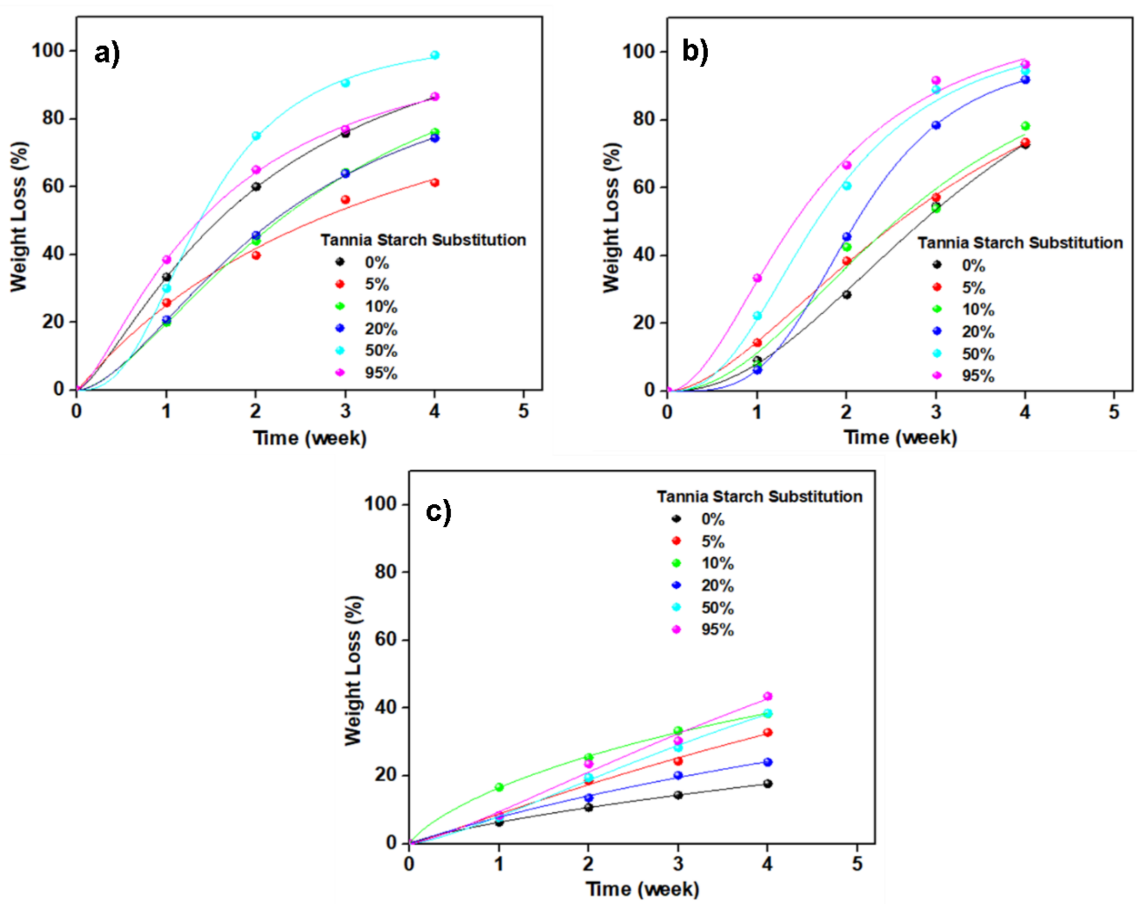

Figure 1. Hill curves of the degradation of cassava – tannia starch bioplastic in **a**) farm soil, **b**) sand, and **c**) compost media

Table 2. Hill parameters of the degradation of cassava – tannia starch bioplastic in various media

Tannia Starch Substitution (wt. %)	Y_{max} (%)	Y_4 (%)	*k* (weeks)	n	R^2
Farm Soil					
0	121.09	86.54	2.04	1.35	0.9999
5	118.34	61.22	3.61	1.02	0.9923
10	117.07	76.05	2.70	1.61	0.9991
20	103.71	74.34	2.29	1.68	0.9952
50	104.71	98.84	1.42	2.60	0.9974
95	108.65	86.57	1.53	1.36	0.9799
Sand					
0	127.25	72.72	3.48	2.15	0.9982
5	125.79	73.42	3.30	1.70	0.9993
10	112.31	78.23	2.82	2.10	0.9583
20	101.09	91.58	2.12	3.59	0.9999
50	109.17	94.44	1.77	2.46	0.9946
95	116.14	96.35	1.64	1.90	0.9937
Compost					
0	164.07	17.66	17.94	0.79	0.9999
5	133.54	62.84	11.28	1.09	0.9898
10	124.47	38.36	11.27	0.77	0.9993
20	107.73	24.05	14.82	0.94	0.9998
50	110.61	38.54	6.35	1.38	0.9994
95	145.20	43.52	7.48	1.29	0.9992

The reduced affinity of this degradation because compost has denser pores than soil or sand, so air cannot get inside to degrade bioplastic. According to **Table 2**, bioplastic decomposes fully in 20 to 51 days in farm soil, 23 to 51 days in sand, and 89 to 252 days in compost medium. That is, bioplastic decomposes more quickly in farm soil and sand. This decomposition time is comparable to Domenek, et al. (2004) research, which found that wheat gluten-based bioplastics decompose completely after 50 days in farmland soil, PLA/algae biomass 5% takes 60 days to decompose in compost media (Kalita et al., 2021), and PPB biodegrades at approximately 100 % in vermicompost within four weeks (Arikan & Bilgen, 2019).

In conclusion, the rate of degradation of bioplastics is not only influenced by the content of microorganisms in the media, but also the maturity of the media, the media pores, and operating conditions. The results of this study have met the standards of bioplastics related to their degradation process, which according to TUV AUSTRIA Belgium (2012), bioplastic requiring at least 90% in two years at preferably 25 °C in soil based on EN 13432:2000 (2000) and EN 14995:2006 (2006) standard, or at least 90% degradation in 12 months at ambient temperature in home composting.

Biodegradation Rate of Bioplastic

The kinetics reaction rate of the bioplastic biodegradation in farm soil, sand, and compost media can be seen in **Figure 2**, while the coefficient of reaction rates for each degradation media is presented in **Table 3**. There are several things that can be reviewed from the reaction kinetic results. First, the reaction rate coefficient (k_r) value of the bioplastic biodegradation process got higher as the amount of tannia starch increased in the bioplastic composition. According to the literature, starch crystallinity slows biodegradation especially enzymatic biodegradation (Lopez-Rubio, Flanagan, Shrestha, Gidley, & Gilbert, 2008; Shrestha et al., 2010). Cassava starch has a relatively high crystalline phase, (Lim et al., 2020; Edhirej, Sapuan, Jawaid, & Zahari, 2017) where increasing the cassava starch content slowed biodegradation, and the crystal structure is difficult to break due to its neat and uniform pattern. Secondly, bioplastics which degraded in sand had a range of k_r values between 0.27758 ± 0.03155 to 0.77647 ± 0.05843 week^{-1}, higher than farm soil and compost which has a range between 0.20072 ± 0.0155 - 0.67133 ± 0.0418 week^{-1} and 0.0443 ± 0.00481 - 0.15779 ± 0.01374 week^{-1}, respectively. This is consistent with the phenomenon shown by the Hill equation (**Figure 1**) where in addition to bacteria, air plays an important role in bioplastic biodegradation. Sand particles allow air to enter the media to do degradation assisted by a limited number of bacteria. Less maturation of compost also causes slow biodegradation in compost media. Third, usually the amylolysis degradation process of complex starch material (more than one material) produces more than one linear line according to the kinetics of first-order reactions (Edwards, Warren, Milligan, Butterworth, & Ellis, 2014; Li et al., 2015). Bu t in **Figure 2 a-c**,

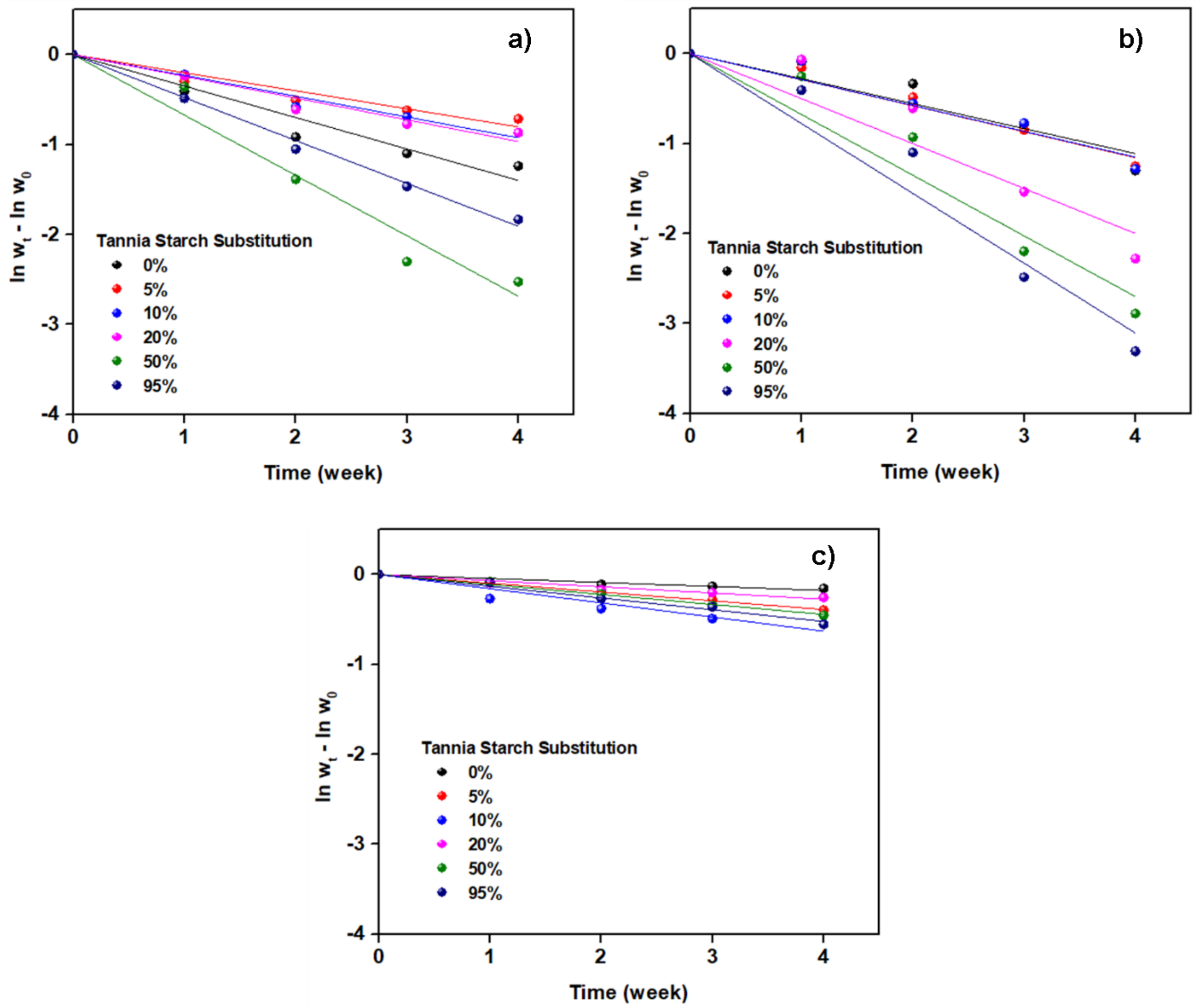

Figure 2. First order of the degradation of cassava – tannia starch bioplastic in **a**) farm soil, **b**) sand, and **c**) compost media

Table 3. Kinetic reaction rate of the degradation of cassava – tannia starch bioplastic in various media

Tannia Starch Substitution (wt. %)	k_r (week^{-1})		
	Farm Soil	Sand	Compost
0	0.34951±0.02558	0.27758±0.03155	0.04430±0.00481
5	0.20072±0.0155	0.28918±0.01746	0.09754±0.00197
10	0.23107±0.01195	0.28773±0.02393	0.15779±0.01374
20	0.2414±0.01534	0.49984±0.05932	0.06857±0.00419
50	0.67133±0.0418	0.67544±0.05933	0.11117±0.00303
95	0.47715±0.01162	0.77647±0.05843	0.13076±0.00566

the value of log-of-slope (LOS) is more directed to the form of a straight line, so it can be concluded that what happened in this biodegradation is a single-phase process. The straight-line LOS plot of the bioplastic biodegradation profile indicates a retrograde process. Retrogradation is the event of the reuniting/re-bonding of amylose and amylopectin molecules that come out of starch granules that have broken/degraded, then form microcrystalline webs, and settle. In this case bioplastics dominated by cassava starch are likely to experience retrogradation as indicated by the length of time of degradation when compared to bioplastics which are dominated by tannia starch.

Morphology of Bioplastic

Figure. 3 shows the morphology of bioplastics degraded for 3 weeks by sand, farm soil, and compost. **Figure 3a** shows that there was nothing on the surface of the bioplastic before it was buried in the various mediums. While in **Figure 3b**, there were sand grains attached to the surface of buried bioplastic specimens.

The picture also confirmed that there was no fungus with only a small number of bacteria attached to the degraded bioplastic surface. This proves that bioplastics buried in sand are degraded by aerobic microbes that utilize the surrounding air that can enter the sand through gaps between the particles. In **Figure 3c**, hyphae from fungi were clearly visible on degraded bioplastic surfaces. In addition, there were agglomerated biofilms, which were believed to be the cause of the degradation process in farm soils. This shows that fungi and bacteria have a higher potential to degrade specimens together. According to some references, filamentous fungi are able to hydrolyze starch into simpler parts (Mellon, Dowd, & Cotty, 2005; Accinelli, & Abbas, 2011). In **Figure 3d**, there were many mineral crystals, and some bedbugs, but no fungus has been found. In addition, there were microbes that are of small quality and do not form biofilms. This proves that compost was still not mature. The microbes in it may still be in the phase of adaptation to the environment, so the degradation process took place slowly.

The bioplastic response to bacteria was strengthened by observing the characteristics of the media, including moisture content and pH, as well as proving the presence of *Pseudomonas* bacteria in the media used, as in **Table 4**. The *Pseudomonas* test was chosen because of the ability of Pseudomonas to degrade biopolymers, which are the building blocks of bioplastics. From **Table 4**, sand has the lowest moisture content compared to farm soil and compost. Whilst, in neutral pH (7-8), the ability of bacteria to degrade tends to increase (Tang et al., 2020). If the pH tends to be acidic, it will reduce the degradation rate of the bioplastic itself, because it will be difficult for bacteria to live in such conditions (Emmadian et al., 2016). *Pseudomonas* testing was carried out using selective media Pseudomonas Cetrimide Agar (Brown, & Lowbury, 1965). This also caused *Pseudomonas* colonies that grew on all media in very large numbers.

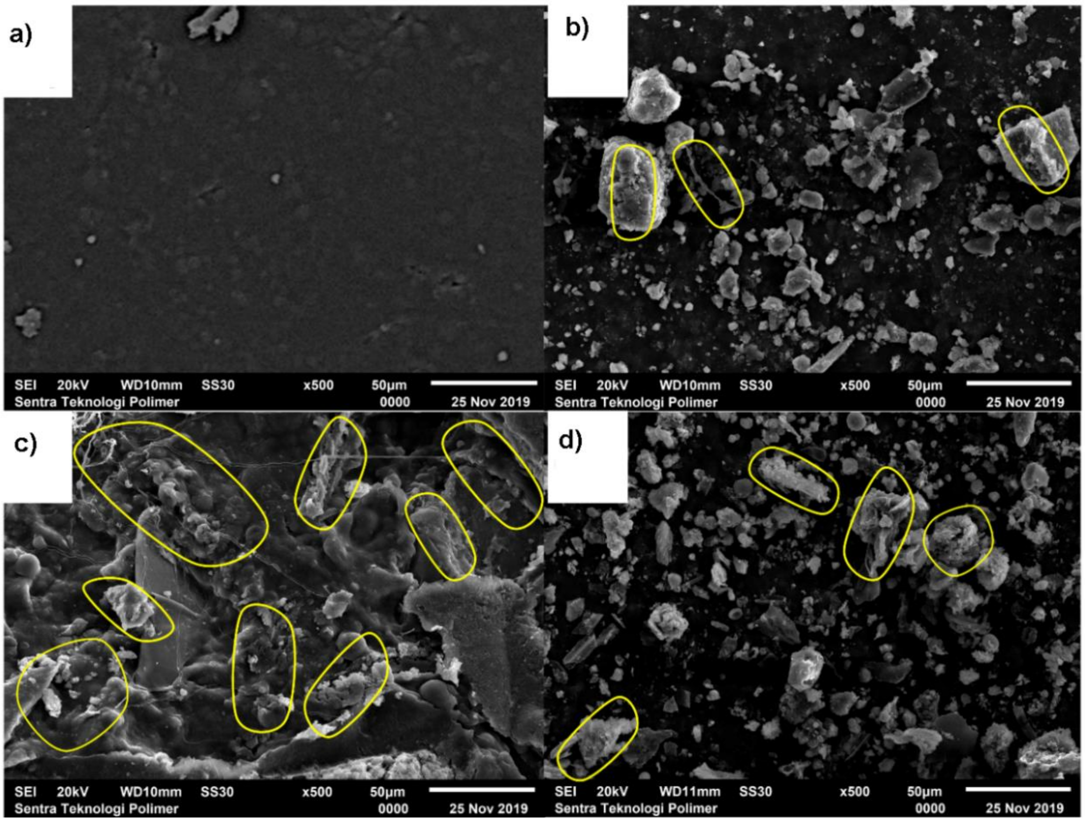

Figure 3. Morphology of cassava – tannia starch bioplastic **a**) before and after buried in **b**) sand, **c**) farm soil, and **d**) compost with 500x magnification. Yellow lines indicate the location of microorganism

Table 4. Moisture content, pH, and Pseudomonas colonies in all biodegradation media

Medium	Moisture Content (%)	pH	Pseudomonas Colonies
Farm Soil	29,19	7,87	TNTC
Sand	19,65	7,25	TNTC
Compost	58,53	7,13	TNTC

Note: TNTC = Too Numerous To Count

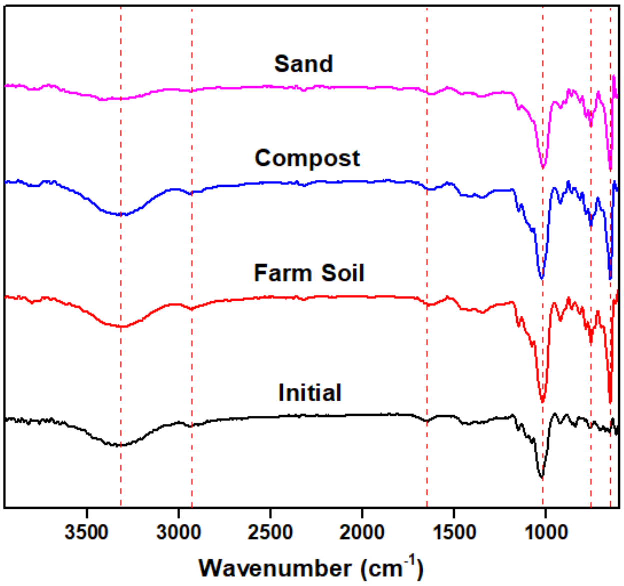

Figure 4. FTIR spectra of cassava – tannia starch bioplastic before and after buried in sand, farm soil, and compost

Chemical Properties of Bioplastic Before and After Degradation Process

FTIR spectra of the cassava – tannia starch bioplastic before and after biodegradation process were analyzed following the microbial degradation resulting decrease in intensity of some bonds and formation of new bonds, as shown in **Figure 4**. The bands of stretching O-H and C-H are on around 3400-3200 cm^{-1} and around 2900 cm^{-1}, respectively. The decreasing O-H peak indicating that the breakdown of O-H bond, while the decrease in C-H stretch peaks indicating the breakdown of C-H bonds. The bands in the region 1700–1200 cm^{-1} apparently arising from minor components such as protein and lipid in the starch. It is also associated with C-O stretching ester carbonyl bond, showing shifting and decrease in the peak intensity which might correspond to the breakdown of ester bond in polymer films after treatment in various media (Dutta, Karak, Saikia, & Konwar 2010). The bands of around 1600 cm^{-1} ascribed to the scissoring of O-H and bonding water molecules. Stretching of C-O from C-O-C in the ring of anhydroglucose detected on the FTIR spectrum of 1025-1018 cm^{-1} indicated the degradation of the polymer chain (Phukon, Saikia, & Konwar, 2012). Peak at 600 cm^{-1} indicated the formation of halo compound which come from degraded bioplastic and I or Br from media. While increase in peak at 750 cm^{-1} indicated the formation of C=C double bond, after they released H atom during biodegradation process.

CONCLUSIONS

Bioplastic biodegradation using different burial media (sand, farm soil, and compost) shows the effect of the strength of the starch structure on the kinetics of the biodegradationrate, and is calculated using the Hills Equation. Bioplastics that are buried in various media all have y_{max} values above 100%, meaning will be completely degraded at infinite time. At the biodegradation time of 4 weeks, the Y_4 value for bioplastics with sand media and farm soil has almost the same range of values, namely 72.72 - 96.35 and 61.22 - 98.84 %, respectively, and followed by compost media with a range of 17.66 - 62.84 %. The value of *k* (half-life) decreases with increasing Y_4 value and the reaction rate constant following the first order. The value of the reaction rate constant from bioplastic biodegradation that is buried with sand media is between 0.27758 - 0.77647 week^{-1}, while 0.20072 - 0.67133 week^{-1} for farm soil media, and 0.04430 - 0.15779 week^{-1} for compost media. The decomposition of starch polymers can be seen from the decrease in the FTIR peak at wavelengths of 3400 - 3200 and 2900 cm^{-1}, which shows the decomposition of O-H and C-H groups due to the presence of microorganisms. In conclusion, microorganisms in various media, both aerobic and anaerobic microorganisms, have an important role in bioplastic degradation so that they can be completely degraded at infinite times.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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