Abstract — Environmental concerns associated with synthetic plastics are detrimental and have made it very crucial to develop biodegradable polymers for commercial and industrial uses. This work investigates the biodegradability of starch (biopolymer) based bioplastics through the soil burial test (SBT) technique. The biopolymeric films were synthesized from 190 and 250 µm biopolymer particulates of manihot esculenta and triticum aestivum. Blends from each particle size were produced in varied proportions with other additives. The biopolymeric films were characterized by physical, physiochemical, thermal, and microstructural tests. The biodegradability of starch-based polymers was determined by a soil burial test for 30 days where topsoil was used as a source of microbial activity. The conventional polyethylene film was also applied to the test. The bioplastic films were observed to have cracks on the surface and became hard and brittle at the end of the testing period. The total weight loss of 46.55–63.77 % was achieved by the bioplastic films. The LDPE film showed no trace of macro-structural changes or any weight reduction throughout the soil burial test. This research concludes that bioplastic films outperformed ordinary plastic films, as they were proven to be biodegradable; and can be employed efficiently in packaging applications.

Keywords — biodegradable, bioplastic, hybrid, starch, soil.

I. INTRODUCTION

Today, sustainable development tops global priorities all over the world. Hitherto, plastic waste is one of the challenges restricting sustainable development and the environment [1]. Plastics are used in a variety of industries and household appliances nowadays. Petrochemical-based plastics are widely used for daily living, primarily for a variety of applications in the packaging industry [2]. Over 120 million tons of plastic are used every year all over the world. The plastics industry has put a lot of effort into developing, formulating, and using durable materials that are better suited to their intended uses. More than 30 million tons of these plastics are being used for various applications in packaging. Despite their many advantages, a large portion of these plastics is non-biodegradable, posing serious environmental issues such as emission of carbon dioxide and accumulation in the environment over a period of time [3]-[4]. Plastic waste over the years has filled landfills [5]. When plastic waste is thrown into landfills, it interacts with water and forms toxic compounds, potentially affecting the quality of drinking water [6]-[7]. Toxic compounds found in some plastic packaging, such as bisphenol A, antimony, and phthalates, can permeate into food [8], [9], causing varying degrees of harm to human health. Chemical contaminants are also produced in huge numbers during the production of plastic items [10]. As a result, the increase in applications of these petrochemical-based synthetic plastics has become serious health, environmental, and economic issue [11]. There are techniques of plastic waste control, such as reusing, burning, and recycling that can help to mitigate these detrimental consequences. Unfortunately, recycling and reuse do not remove harmful compounds or non-biodegradability, and incineration pollutes the environment. As a result, efforts are made to cut down on the usage of these plastics. Bio sourced plastics made from local materials appear to be a viable alternative to petrochemical plastics [12], [13]. Bioplastic is a substance derived from natural biological resources [14]. Bio-sourced bioplastics are made from renewable sources such as polysaccharides, proteins, lipids, or substances produced by microorganisms [15]-[18]. Starch-based plastics are the most frequently used bioplastics today, accounting for over half of the total bioplastics market. Bioplastics made from starch are simple to make and offer a wide range of uses in packaging [19], [20]. Biodegradable plastic research has advanced significantly in recent years [21]-[24]. Several tests were conducted to explore the various physical, mechanical, and thermal characteristics of a biopolymer made from manihot starch for diverse applications [25]. Despite substantial research on starch-based bioplastic films, [26]-[27] there has been no study of hybrid starch-based films for packaging applications from manihot esculenta (ME) and triticum aestivum (TA), botanically representing cassava [28] and wheat [29] starch, respectively. As a result, the current study will concentrate on combining ME and TA starches. The goal of this study is to investigate the biodegradability of starch-based bioplastic films made in the lab from local ME and TA starches with suitable additives like glycerol, acetic acid, and distilled water utilizing soil burial tests. Several physical, chemical, and thermal testing were performed on the bioplastic films, including water absorption, FTIR, SEM, and biodegradability tests. The quantitative breakdown of bioplastic was determined using the soil burial test method. Biodegradability was measured by observing any physical change, such as macrostructural changes and weight loss of the bioplastics for 30 days.
II. MATERIALS AND METHODS

A. Materials

The creation of biodegradable polymeric films necessitates the use of TA grains and ME tubers to produce natural starch. These resources came from a variety of areas in Nigeria; ME tubers were purchased from the Mile 12 market in Lagos, while TA grains were sourced locally from Sudan Savanna in Sokoto. Other polymeric ingredients which include white vinegar, glycerol distilled water, and 5% acetic acid, were acquired from a chemical market in Bariga, Lagos.

B. Method of Starches Extraction

The TA starch was unearthed by steeping the grains in clean water at room temperature for three days, to fully ferment and soften enough to grind. The water was changed regularly at 24 hours intervals. Afterward, the grains were carefully washed, before being transferred into a blender in batches for liquidizing with water. The liquidizing TA to water ratio is 1:10 (w/w). After thoroughly liquefied, more water was added to the slurry (about eleven times its weight), stirred, and filtered into a clean container using a fine mesh strainer of 2 μm size and allowed to settle for 6 hours. The filtrate was retrieved by decanting water gently. The wet starch was spread on a succulent cloth wrapped in a flat shallow bowl and allowed to dry at room temperature for one hour to rid of the remaining water. It was then sun-dried on aluminum foil for 2 days before storing in a container. Similarly, ME starch was processed from ME tubers, which were peeled and cut into small pieces and ground. The procedures used for TA starch processing were also adopted for ME starch, as presented in Fig. 1–3.

C. Bioplastic Film Preparation

The preparation of the starch-based bioplastic films commenced by adding 100 mL distilled water to a 400 mL beaker, homogenous starch powders was measured and added
proportionately in a 400 mL beaker, in order to determine the combination of bioplastic film with better physical, mechanical and biodegradable properties, eight (8) different samples of ME and TA starches were measured using an electronic analytical balance at different standard sizes (i.e., 250 µm, and 190 µm in Table II & III, respectively), giving a total of sixteen (16) formulations of bioplastic starch films.

TABLE II: VARIED FORMULATION USED FOR THE PRODUCTION OF BIOPLASTIC FILMS WITH 250 µM

| Sample design | S1  | S2  | S3  | S4  | S5  | S6  | S7  | S8  |
|---------------|-----|-----|-----|-----|-----|-----|-----|-----|
| ME Starch (g) | 15  | 13.5| 12  | 10.5| 9   | 7.5 | 6   | 4.5 |
| TA Starch (g) | 0   | 1.5 | 3   | 4.5 | 6   | 7.5 | 9   | 10.5|

Glycerol and 5% acetic acid of 10 mL each (constant volume) were also added to the beaker. The beaker was placed on a heater plate attached to a magnetic stirrer (Fig. 5a), the mixture was then heated on the heater which was set at 200 °C, and was stirred continuously at 9 rad/s for 10 min to form an opaque gel. The gel was then poured onto plate covers which were used as molds and spread uniformly, samples were then dried in the oven at 60 °C for two (2) hours. A dried bioplastic film is shown in Fig. 5b.

Fig. 5. Film preparation (a) mix on hot magnetic steerer, (b) Dried bioplastic film

III. DETERMINATION OF BIOPLASTIC PROPERTIES

A. Determination of Thickness Test

The thicknesses of the films were measured with a digital vernier caliper in accordance with D6988-13 [30]. For each film, three random measurements were taken, and an average value was determined.

B. Determination of Specific Gravity and Density Test

The D792-20 [31] standard was used to test the specific gravity of the bioplastic films measured 10 cm by 1 cm. The mass of each film was weighed in the air with a conventional chemical digital weighing scale precise to 0.1 mg. They were then immersed in distilled water to estimate the apparent mass of the films (1) and used to compute the specific gravity:

\[ \text{Sp gr} \ 23/23 \degree \text{C} = \frac{a}{a+w-b} \]

where \(a\), \(b\), and \(w\) are the apparent mass of specimen in air, the apparent mass of a fully immersed specimen and a partially immersed wire in liquid, and the apparent mass of partially immersed wire, respectively.

Invariably, the density of the bioplastic films is calculated from the specific gravity values according to the [31] standard as contained in (2).

\[ D_{at \ 23 \degree \text{C}} = \text{Sp gr} \ 23/23 \degree \text{C} \times 1 \ g/cm^3 \]  

C. Fourier Transform Infrared Spectroscopy Test

The functional groups on the surface of the bioplastic were identified using the FTIR spectroscopy approach. In accordance with E1252-98, [32] standard, functional groups of bioplastics were investigated using a Fourier transform infrared spectroscopy (IR Prestige-21 Shimadzu).

D. Scanning Electron Microscopy with Energy Dispersive X-ray Spectroscopy (SEM/EDX)

Morphological investigations were carried out on the bioplastic films using a scanning electron microscope to determine the dispersion degree of particles and their morphological characteristics in order to explain and analyze the properties and, as a result, to judge the performance of the biopolymers. The elementary analysis was carried out using an EDX spectrometer in accordance with E1508-12a, [33] standard.

E. Biodegradability Test

A simple soil burial test, D570-98, [34], was used to assess the biodegradability of the bioplastic samples. Bioplastic samples (5×5 cm) were buried in natural soil in plastic containers at a depth of 5 cm below the soil’s top surface and incubated at room temperature without any enzyme activity or composting substances.

The weight loss (percent) of the samples at 2 days intervals after soil burial was used to determine the degree of biodegradability of the bioplastics. The samples were cleaned by wiping lightly with tissue to remove soil debris from the surface of the samples after each interval of soil burial, then, dried at room temperature in a desiccator till they attained a consistent weight. The weight change (loss) before and after burial was measured and compared to determine biodegradability. Equation (3) is used to compute the weight losses in the buried samples.

\[ \text{Weight Loss (\%) = } \left( \frac{w_0 - w_1}{w_0} \right) \times 100. \]  

where \(w_0\) and \(w_1\) are weights of the samples before and after burial.

IV. RESULTS AND DISCUSSIONS

A. Elemental Analysis of Starch via X-ray Fluorescence (XRF) Spectrometry

The percentage concentration of elements in TA starch is 3.86% Fe, 1.25% Zn, 0.92% MgO, 4.41% S, 42.4% SiO2, 8.18% Al2O3, 8.27% P2O5, 0.39% Na2O, 3.93% CaO, 22.72% K2O, 0.22% TiO2, and 3.42% MnO, while that corresponding elements in ME starch is 2.23% Fe, 0.94% Zn, 0.67% MgO, 0.92% CaO, 32.22% SiO2, 9.3% Al2O3, 9.23% K2O, 0.4% MgO, 1.25% CaO, and 0.94% Zn.
6.04% S, 57.68% SiO₂, 4.91% Al₂O₃, 16.99% P₂O₅, 0.31% Na₂O, 4.35% CaO, 3.62% K₂O, 0.29% TiO₂, and 1.98% MnO. The oxides in trace quantity in both starches include that Ti, Na, Mg, and the Zn element. The dominant oxides in TA starch in descending order are SiO₂, K₂O, P₂O₅, and Al₂O₃, while the corresponding oxides in ME starch are the SiO₂, P₂O₅, K₂O, S, and Al₂O₃, CaO. Silicon dioxide is known for strength, hardness, improving the setting, and curing time. Alumina (Al₂O₃), and amphoteric (ability to react with acids or bases to produce salt and water) oxide, improves the fire resistance, and flexural strength, but decreases the setting and/or curing time in wet composites. Phosphorus pentoxide (P₂O₅) accelerates a drying agent that fosters the rate of dehydration.

B. Morphological Analysis of Starch via Scanning Electron Microscope (SEM)/ Energy Dispersive X-Ray (EDX)

The micrographs in Fig. 9–12 reveal the presence of ridges and grooves in the microstructure of the films showing an irregular microstructure of selected bioplastics films. The surface microstructure also exposes the roughness of the bioplastic films (consisting of granules and/or leftovers of the starch particles) which implies uneven gelatinous, liquefaction, and dispersion of starch granules in the bioplastic film during the formation process. The EDX analysis disclosed large proportions of carbon and oxygen content in bioplastic films accruing from starch particles which confirms the presence of residual starch particles in the bioplastic films. Likewise, Garcia-Hernandez, Vernon-Carter, and Alvarez-Ramirez et al. [35] observed a residual component of starch particles in the surface microstructure of biopolymers which suggests irregular starch gelatinized throughout the manufacturing process, owing to some insoluble remains from starch granule swelling.

Voids are also detected in the surface microstructure, in the form of black visible holes. The presence of defects such as voids, ridges, grooves, and holes in the microstructure of the bioplastic films indicates the possibility of poor molecular bonding between the starches. Interfacial interactions between the film components can be improved by the addition of filler compounds (e.g., graphene oxide) into the biopolymer film to ensure better bonding [36].

Fig. 9(a). SEM image of S1 bioplastic film.

Fig. 9(b). EDX analysis of S1 bioplastic film.

Fig. 10(a). SEM image of S4 bioplastic film.

Fig. 10(b). EDX analysis of S4 bioplastic film.

Fig. 11(a). SEM image of S6 bioplastic film.
C. Bioplastic Film Thickness

Conventional plastic films have a typical thickness of 0.0127–1.016 mm. Nevertheless, the bioplastic films formed had an average thickness of 0.316 mm. The thickness range of bioplastic films produced is from 0.28–0.36 mm, indicative of useability for carrier bag production. In a comparable account, Resianingrum, Atmaka, Khasanah, Kawiji, Utami, and Prasptiangga et al. [37], obtained ME starch film thicknesses within the range of 0.144 to 0.189 mm. Hence, this study had achieved higher bioplastic films’ thickness values, attributable to the inclusion of the TA starch.

D. Bioplastic Film Specific Gravity and Density

Another essential physical property of bioplastic films to look into is density, which refers to how tightly the material’s particles or atoms are packed. The bioplastic films from this study have a density of 1.233–1.3235 g cm⁻³, which is higher as compared to conventional polyethylene films, with a density ranging from 0.917–0.930 g cm⁻³. It is evident, therefore, that the bioplastic films produced in this study have more closely packed molecules than polyethylene films. Abdullah, Ismail, Nurul, Olaya, Nasution, Oyekanmi, and HPS et al. [38], also upholds this observation in a report with a density of 1.45 g cm⁻³ for starch-based films. This result from the starch content of bioplastic film contains, which has a high viscosity as well as high swelling power in the water. This nature of starch-based bioplastics makes them ideal for various applications such as food packaging, compost bag manufacturing, etc.

E. Fourier Transform Infrared Spectroscopy

The functional groups of bioplastics were investigated using a Fourier transform infrared spectroscopy (IR Prestige-21 Shimadzu) and presented in Fig. 13. Functional groups and potential chemical changes produced by the addition of plasticizers and fillers were detected using FTIR analysis which enables the identification of these functional groupings to be done quickly, accurately, and efficiently [39]. FTIR analysis on the bioplastic films (Fig. 13) shows major functional groups present by their peak wavelengths. One of the major peaks identified from all the FTIR spectra was the peak corresponding to –CO group. This peak was observed in each of the spectrums at 1103 cm⁻¹, 1034 cm⁻¹, 1040 cm⁻¹ and 1028 cm⁻¹. Accordingly, peaks formed in this range are attributable to the stretching of anhydro-glucose ring (C-O).
properties [40]. The bond is usually produced in carbohydrates’ structure due to the stretching of C-O-H groups [40]. The peaks between 1400 cm⁻¹ and 1636 cm⁻¹ wavelengths were also detected and ascribed to the –CH group. Other peaks discovered in each bioplastic film spectra, for instance, the peaks around the region below 800 cm⁻¹ correlate to the pyranose ring skeletal vibrations in the starch glucose unit [41]. Peaks corresponding to the –OH group were also found between 3390 cm⁻¹ and 3626 cm⁻¹ wavelengths. Sultan, and Johari et al. [42], claim that the peaks in this region correspond to hydrogen-linked hydroxyl group (O-H) due to the intricate vibrational stretching that naturally occurs in the carbohydrate structure. It is, therefore, a shared belief that this group is responsible for the intermolecular hydrogen bonding in bioplastic films between the starch particles, glycerol, and other additives [41]. Worth to note is that hydroxyl groups are strongly linked to water molecules initially adsorbed on starch particles. Additional water absorbed is held loosely till all available hydroxyl groups have been used up [43]. Consequently, moisture is absorbed majorly by the presence of the hydroxyl groups in the starch particles. Also, peaks were identified at 1466 cm⁻¹, 1444 cm⁻¹, 1450 cm⁻¹ and 1465 cm⁻¹ in all analyzed bioplastics samples which are assigned to –CH group. Peaks in this region are known to be instigated by CH₂ bending vibrations of the starch present in films. Other peaks were also discovered in each bioplastic film spectra. Muscat, Adhikari, Adhikari, and Chaudhary et al. [44], argue that spectra peaks in the region below 800 cm⁻¹ correspond with the skeletal vibrations of the pyranose ring in a starch’s glucose unit. These results showed that similar peaks were identified in all of the starch-based bioplastic films.

F. Biodegradability Examination

Fig. 14 and 15 show the results of the biodegradation of starch-based biopolymer films as a function of weight loss over time (days), in the soil burial system. The biodegradation mechanism of polymeric materials is substantially impacted by the microbiological conditions of polymeric materials, according to a previous study [44], [45]. It has been earlier reported that bacteria and fungi in the soil environment can destroy starch’s primary components [46]–[48].

From day 0 to day 2, all of the bioplastic films showed an initial increase in weight, as illustrated in the figure below. This was most likely due to the soil absorbing moisture. Starch is naturally hydrophilic, which means it can easily absorb water. The water received by the films from the soil induced an expansion of the films from day 0 to day 2, as illustrated in the diagram above. The weight of the bioplastic films has also decreased since day two. This is thought to be due to the bioplastic films’ initial absorption. Similar research studies have found that the biodegradation process is influenced by the activity of moisture (water) and bacteria in the soil on the substrate [49]. Moisture is an important component in the growth and effectiveness of microorganisms.

As a result, higher water absorption by bioplastics due to high starch content in bioplastic films should weaken the bonds and render the bioplastics mushy, allowing a faster microbial attack. This would almost certainly increase the rate at which bioplastics degrade [50], [51]. From day 2 to day 30, the number of weight losses increased each day, indicating that the bioplastics were degrading faster as the burial duration increased. The key characteristic of a polymer that can be destroyed spontaneously is that it has a hydroxyl group (-OH), which is easily degraded by microbes [52]. The hydroxyl group in starch is known to activate the polymer's hydrolysis reaction, making it easier for water (moisture) to be absorbed from the soil and for microbes to operate. Changes in macrostructure were also influenced by burial in soil. Following the completion of the testing procedure, visual changes to the samples were observed, for example, the samples began to disintegrate when touched. The bioplastic samples observed every two days began to change physically, with fissures appearing on the sample's surface. The sample's form then became brittle on the 30th day. Similarly, researchers have observed that bioplastic films examined through soil burial testing shrank in size after the test was completed, and the samples became rigid and fragile [52]. This could possibly be linked to the actions of numerous microbes (fungi and bacteria) on bioplastic films, which resulted in the macrostructure of the bioplastic samples being damaged. In a 30-day soil burial period, the biodegradability (percent) of starch-based films ranged from 49.25 to 58.82 %, and 46.55–63.77 % for various bioplastic film combinations made from 250 µm and 190 µm starch particle sizes, respectively. During the soil testing approach, however, the typical plastic sheets exhibited no signs of macrostructural changes or weight loss.

Fig. 14. Biodegradability as a function of soil exposure duration of selected (S1, S4, S6 & S8) bioplastic films.

Fig. 15. Biodegradability as a function of soil exposure duration of selected (S1, S4, S6 & S8) bioplastic films.
G. Rate of Soil Moisture Removal

Evidently, the rate of moisture exclusion from the cultivated soil for the bioplastic films blends as contained in Fig. 16 and 17, is sporadic from inception. The rate of moisture removal from the first day through the fifth day is approximately 6/day. The moisture loss during this period is mostly contained at the soil surface. The decrease in the surface moisture led to a drastic reduction in the moisture loss, after the fifth day of soil exposure.

Fig. 16. Soil moisture removal against the cultivation duration of selected (S1, S4, S6 & S8) bioplastic films.

Fig. 17. Soil moisture removal against the cultivation duration of selected (S1, S4, S6 & S8) bioplastic films.

Also, the bioplastic film rate of moisture absorption is faster at the early (1–5) days of soil exposure, after the trend of the bioplastic films rate of moisture intake started declining, attributable to samples approaching saturation attainment. On the thirtieth day of soil exposure, it could be deduced that the bioplastic films have reached saturation in moisture absorption. Conversely, the control plastic films exhibit little or no evidence of moisture ingestion throughout the period of soil exposure, an indication of a lack hydroxy group with resultant hydrophobic and non-biodegradable nature.

V. Conclusion

In this study, bioplastic films were successfully made from ME and TA starches. The characteristics of the synthesized films were equivalent to those of commercially available packaging materials. Bioplastic films ranged in thickness from 0.28mm to 0.35mm, with densities ranging from 1.233 to 1.3235g/cm³. The bioplastics’ water absorption ranged from 67.44 percent to 78.42 percent, and their tensile strength was 0.36 to 2.3 MPa. Furthermore, the bioplastics were discovered to be soil degradable. The films’ biodegradability ranged from 46.55 percent to 63.77 percent over 30 days intervals.

According to the results of this study, it is possible to infer, therefore, that bioplastics are a better option to LDPE and HDPE plastic films because of their superior biodegradability features. Bioplastics’ low tensile qualities and the high rate of water absorption, on the other hand, limit their use as a food packaging film to replace conventional films. As a result, modifying starch properties, such as blending or hybridizing starch materials with other biomaterials, as well as adding additional plasticizers that are less hydrophilic (e.g., citric acid), should be considered for increasing the spectrum of uses of the films.

Acknowledgment

The authors’ unanimous gratitude goes to Messrs. Isaac Oduaran, and Joel O. Ugwuozor of the Materials Laboratory Section, Department of Metallurgical and Materials Engineering, University of Lagos, for their assistance during the processing phase of materials.

Funding

The research acknowledges no sponsorship or any financial support whatsoever.

Conflict of Interest

The authors declare that they do not have any conflict of interest.

References

[1] Baran B. Plastic waste as a challenge for sustainable development and circularity in the European Union. Ekonomia i Prawo, Uniwersytet Mikołaj Kopernika, 2020;19(1):7-20. doi: 10.12775/EP.2020.001.
[2] Mileonis A, Ruffilli R, Bayer IS. Superhydrophobic nanocomposites from biodegradable thermoplastic starch composites (Mater-Bi®), hydrophobic nano-silica and lycopodium spores. RSC Advances, 2014;4(65):34395-34404. https://doi.org/10.1039/C4RA04117H.
[3] Emadian, SM, Onay TT, Demirel B. Biodegradation of bioplastics in natural environments. Waste Management, 2017;59:526-536. doi: 10.1016/j.wasman.2016.10.006.
[4] Webb HK, Arnott J, Crawford RJ, Ivanova EP. Plastic degradation and its environmental implications with special reference to poly (ethylene terephthalate). Polymers, 2013;5(1):1-18. https://doi.org/10.3390/polym5010001.
[5] Breslin V, Reaven S, Schwartz M, Swanson L, Zweig M, Bortman M, Schubel J. Secondary materials: Engineering properties, environmental consequences, and social and economic impacts. Final report (No. NYSERDA-93-16), State Univ. of New York, Stony Brook, NY, (United States). Waste Management Inst., 1993. https://digital.library.unt.edu/ark:/67531/metadc1275356/.
[6] Schwab O, Bayer P, Jurasek R, Verones F, Hellweg S. Beyond the material grave: Life Cycle Impact Assessment of leaching from
degradation in soil. *Nigerian Journal of Biotechnology*. 2009;20(1):28-33. print ISSN: 0189-1731. http://www.ajol.info/index.php/njb/index and www.biotechsoctyng.com.org.

[47] Stevens, E.S.; & Goldstein, N. How green are green plastics? *Biocycle*. 2002;43(12):42-45. https://www.bpiworld.org/resources/Documents/How%20Green%20Are%20Your%20Plastics%20by%20BioCycle.pdf.

[48] Shen J, Bartha R. Priming effect of glucose polymers in soil-based biodegradation tests. *Soil Biology and Biochemistry*, 1997;29(8):1195-1198. https://doi.org/10.1016/S0038-0717(97)00031-X.

[49] Lyoo WS, Yeum JH, Kwon OW, Shin DS, Han SS, Kim BC, Noh SK. Rheological properties of high molecular weight (HMW) syndiotactic poly (vinyl alcohol) (PVA)/HMW atactic PVA blend solutions. *Journal of applied polymer science*, 2006;102(4):3934-3939. doi:10.1002/app.24223.

[50] Obasi HC, Igwe JO, Madufo, IC. Effect of soil burial on tensile properties of polypropylene/plasticized cassava starch blends. *Advances in Materials Science and Engineering*, 2013b. https://doi.org/10.1155/2013/326538.

[51] Darni Y, Dewi FY, Lismeri L. Modification of sorghum starch-cellulose bioplastic with sorghum stalks filler. *Journal of chemical engineering and environment*, 2017;12(1). http://journal.unsyiah.ac.id/RKL/article/view/5410.

[52] Leja K, Lewandowicz G. Polymer biodegradation and biodegradable polymers-a review. *Polish Journal of Environmental Studies*. 2010; 19(2). http://www.pjoes.com/Polymer-Biodegradation-and-Biodegradable-Polymers-a-Review,88379,0,2.html.