

# Bioprospection of Indigenous Molds Obtained from *Diospyros javanica* Leaves as Agents of Plastic Biodegradation

Muhammad Fahmi<sup>1\*</sup>, Anisa, Istiana Putri<sup>1</sup>, Farra Dibha Nur Hakiki<sup>1</sup>, Fredrick  
Liui<sup>1</sup> and Ni'matuzzahroh<sup>1</sup>

<sup>1</sup>Faculty of Science and technology, Universitas Airlangga (UNAIR), Kampus C Jl. Dr. Ir. H. Soekarno, Surabaya, East Java 60115,  
Indonesia.

## ARTICLE INFO

### Article history:

Received 9 October 2024  
Revised 14 December 2024  
Accepted 13 May 2025  
Published 27 June 2025

### Keywords:

Area Specific Resistance  
Ba(Ce,Zr)O<sub>3</sub>  
Distribution  
LSCF  
Relaxation Times

### DOI:

10.24191/scl.v19i2.6870

## ABSTRACT

Plastic is a material that is difficult to decompose because it has long polymer chains, high molecular weight, and hydrophobic properties. Plastic degradation is often carried out chemically, but this results in various environmental problems such as the release of toxic by-products and pollutants. The environmentally friendly solution to reduce plastic is by natural decomposition with the help of microorganisms which is known as biodegradation. This research provides an appropriate solution to the problem of plastic degradation by utilizing indigenous mold obtained from the *Diospyros javanica* tree. Biodegradation tests were carried out to determine the ability of plastic degradation by these indigenous molds which are assumed to be efficient in an environmentally-friendly plastic degradation. Indigenous molds were identified and assumed to be three types of mold isolates of the genera *Humicola*, species *Aspergillus flavus*, and *Aspergillus niger*. Biodegradation analysis was carried out using Fourier Transform Infrared (FTIR) analysis in order to detect changes in functional groups (chemical compounds and bonds) and Scanning Electron Microscope (SEM) analysis to help visualize the plastic surface of the test results. The results show that the genera *Humicola*, *Aspergillus flavus*, and *Aspergillus niger* have potential for plastic biodegradation. The DJ1 isolate (*Humicola* genus) had the largest percentage of plastic degradation efficiency, namely 23.96 % after 15 days of incubation. The results within this research suggests that *Humicola* shows a great potential to fill in a role in plastic biodegradation.

<sup>1\*</sup> Corresponding author. E-mail address: muhammad.fahmi-2021@fst.unair.ac.id  
<https://doi.org/10.24191/scl.v19i2.6870>

## INTRODUCTION

Plastic has unique physical and chemical characteristics, making it a global commodity. The global plastic volume in 2022 was estimated to have reached 400.3 million tons, and it is predicted that by 2050 the global plastic volume will reach 800 million tons [1]. Global plastic emission in water bodies were estimated to range from 9 to 23 million metric tons. This amount is a threat to the world, because in some of its applications, plastic has negative impacts due to its production process and waste management [2]. The World Wide Fund (WWF) suggests that plastic and microplastic accumulation can potentially damage both marine and land organisms. Ekanayaka *et al.* suggested that plastics possess high tolerance towards naturally occurring degradation processes due to its long polymer chain, high molecular weight, and its hydrophobicity [3]. According to Pilapitiya and Amila, plastic degradation takes around 100 to 1000 years to degrade, causing the accumulation of plastic waste globally [1]. This includes Polyvinyl-chloride (PVC), Polyethylene-terephthalate (PET), and Polyethylene (PE), the largest plastic component globally [4]. Environmental physical and chemical factors break down plastic into microplastics, which is toxic to the environment and its organisms. Upon ingestion, microplastics interfere with important biological processes in the human body and can cause disruption of the endocrine, immune system; can have a negative impact on mobility, reproduction and development; and can cause carcinogenesis [5].

Several alternative methods have been practiced to accelerate the plastic degradation process, such as photodegradation, chemical decomposition, high-temperature decomposition, gamma irradiation, and biodegradation using biological additives or microorganisms [3]. Among these methods, biodegradation has the lowest cost and energy consumption and is the most environmentally friendly option, because it does not produce toxic by-products [3]. Biodegradation can also be done *in situ*, because it is part of a natural process [1]. Wilkes and Aristilde [6] also suggests that microorganisms can further break down microplastics, which solves the previous issue of microplastic by-products in other plastic degradation methods.

Biodegradation using bacteria and fungi has been shown to have the ability to break down solid elements into non-toxic elements [7]. Fungi have greater potential in decomposing plastic, especially PE compared to bacteria [8], because of their wide distribution and niche coverage, high survival ability, and resistance to environmental conditions [7]. Molds (filamentous fungi) possess advantages such as a strong enzymatic system, non-substrate-specific, hydrophobic secretion to attach on hydrophobic substrates, and the ability to penetrate three-dimensional substrates [9]. The enzyme complex in molds is regulated by Cytochrome P450 family (CYP) in the endoplasmic reticulum, and is connected to the cytosol, and environmental membranes. CYP regulates the catalysis of various enzymatic reactions, including epoxidation, hydroxylation, dealkylation, sulfoxidation, desulfurization, deamination, dehalogenation, and N-oxide reduction [9]. Molds have also developed the adaptational abilities to withstand environmental changes and tolerate various pollutants, thus playing an important role in the degradation and demineralization of various environmental pollutants [10]. Molds secrete digestive enzymes through the exocytosis process from their hyphae to break down macromolecules into organic compounds [10]. In several previous studies, molds for plastic degradation were explored in soil and saline areas such as mangroves or oceans, and not many studies have isolated them directly from plastic [11,12,13].

In an ecophysiological sampling activity of *Diospyros javanica* plants, molds were found growing on stored leaf samples that were left for months in plastic. The molds grew out and penetrated the plastic wrap. The discovery of these molds gave rise to the assumption of the mold's potential in plastic biodegradation. The results of this research could contribute in an effort to realize the 12<sup>th</sup> point of Sustainable Development Goals (SDGs) which is handling plastic production waste responsibly.

## EXPERIMENTAL

### *Material Collection and Culture Cultivation*

Indigenous molds were isolated aseptically from *Diospyros javanica* leaves, into nutrition-rich Potato Dextrose Agar (PDA) medium, using inoculation loop. After pure cultures were obtained, they were then rejuvenated into slanted agar tubes containing 1 mL of PDA, and kept under room temperature.

### *Fungal Characterization*

For macroscopic morphological observation, the top-verse and reverse orientations of each colony's expressions were photographed. For the microscopic morphological characteristics, the slide culture method was used. A U-shaped bar was immersed in a Petri dish. An object glass was put on the U-shaped bar. A PDA cutting of 1 cm<sup>2</sup> was placed onto the object glass, followed by inoculation of the mold isolate onto the PDA, and covered with a cover glass. Finally, distilled water was poured into the Petri dish to immerse the U-shaped bar, and the Petri dish was sealed and incubated. After a week of incubation, the object glasses with mold hyphae attached to them were moved onto another object glass stained with a drop of lactophenol blue, then observed using an optical microscope under 400x magnification. The cultures were then identified based on the guidebook of "Pengenalan Kapang Tropis" by Gandjar *et al.* [14].

### *Plastic Biodegradation Assay*

Plastic biodegradation assay was carried out according to methods done by Malachová *et al.*, with some adjustments [15]. In the biodegradation assay, plastic sheets of PE were cut into 1 cm<sup>2</sup> pieces. These plastic pieces were sterilized by immersion in ethanol (70% v/v) inside a Falcon tube, and vortexed at 120 rpm for 10 minutes. Next, the pieces were rinsed by another immersion in distilled water (dH<sub>2</sub>O) inside a Falcon tube, and vortexed for another 10 minutes at 120 rpm. Then, excess water was wiped off, and plastic pieces were weighed in replicates of five as "initial weight". Each group of plastic pieces were further sterilized in Petri dishes under UV light for 1 hour and aseptically inserted into glass vials for the assay.

Biodegradation assay was carried out in Bushnell Haas' broth medium as a nutrient-deficient/medium, containing 0.2 g/L of magnesium sulphate (MgSO<sub>4</sub>), 0.02 g/L of calcium chloride (CaCl<sub>2</sub>), 1g/L each of ammonium nitrate (NH<sub>4</sub>NO<sub>3</sub>), monopotassium phosphate (KH<sub>2</sub>PO<sub>4</sub>), dipotassium phosphate (K<sub>2</sub>HPO<sub>4</sub>), and 0.05 g/L of ferric chloride (FeCl<sub>3</sub>). The mineral media used does not contain any carbon source, therefore yeast extract of 100 mg/L was added in order to give rise to the initial growth of the spores. All media mixtures were sterilized in an autoclave, prior to inoculation. The inoculation of molds was performed using spore suspensions in 15 mL of saline water (NaCl 0.85% w/v). Optical density at wavelength of 600 nm (OD<sub>600nm</sub>) measurement of the three spore-suspensions was measured using a spectrophotometer and set at standard value of 0.1. Cultures for biodegradation assay were incubated in a 30 mL vial, on a *lab shaker* set to 120 rpm for 8 hours daily up to 15 days of biodegradation assay.

After the 15-days of incubation period, plastics were washed by immersion in sodium dodecyl sulfate (SDS) inside a Falcon tube, and vortexed at 120 rpm for 10 minutes. Next, the plastics were washed by immersion in ethanol (70% v/v), and vortexed at 120 rpm for 10 minutes. Finally, they were rinsed by immersion in distilled water (dH<sub>2</sub>O), and vortexed at 120 rpm for 10 minutes. The aseptic plastics were then weighed in groups of five fragments to determine the post-degradation weight. They were then sealed into Petri dishes, and kept aseptically, until due time for Scanning Electron Microscope (SEM) and Fourier-Transform Infrared (FTIR) characterization. Percentage of degradation was calculated using the formula of "degradation efficiency" by Rohmah *et al.* [12], as presented in Equation 1.

$$\text{Degradation Efficiency} = \frac{W_1 - W_0}{W_1} \times 100\%. \quad (1)$$

Description:

W1= Initial plastic dry weight

W0= Plastic dry weight post-incubation

### ***pH Measurement of Biodegradation Assay Media***

pH-level measurement was done on the *Bushnell Haas* broth used for biodegradation assay. The test was carried out prior to the biodegradation assay (day 0) and after the degradation assay (day 15), for all test groups and control. The measurement was performed using MColorpHast™ test strips.

### ***Biomass Measurement***

Biomass measurement for each test group was taken after 15 days of incubation. Empty Falcon tubes were weighed and marked. Liquid medium containing molds were poured into each Falcon tubes accordingly, which were then centrifuged at 5000 rpm for 15 minutes. The supernatant was disposed of, and Falcon tubes containing the pellet were dried using an oven at 90°C until the pellets dry. The dry pellets were weighed inside the tube, then subtracted by the initial (empty) Falcon tube weight. Mold biomass was calculated as the dry weight of mold-isolate pellet, subtracted by the dry weight of control pellet. The subtraction was done because the minerals inside the Bushnell Hass broth had formed into mineral sediments after the autoclaving process during medium preparation.

### **Fourier Transform Infrared (FTIR) Characterization**

Samples for FTIR characterization were chosen from the replicates with the highest degradation efficiency score, for each mold group. ATR-FTIR were scanned at frequency of 1000 - 3500 Hz, and displayed as transmission percentage (%), at 8 ms<sup>-1</sup> resolution.

### **Scanning Electron Microscopy (SEM) and Stereo-microscopy Visualization**

Samples for SEM-EDX visualization were chosen from the mold group with the highest degradation efficiency percentage. The sample was further cut into the appropriate size. The observation was carried out using Thermo Scientific SEM, at 15,000x magnifications. Stereo-microscopy photographs were captured using Dino-Lite Digital Microscope, under 150x magnifications.

## **RESULTS AND DISCUSSION**

### ***Material Collection and Culture Cultivation***

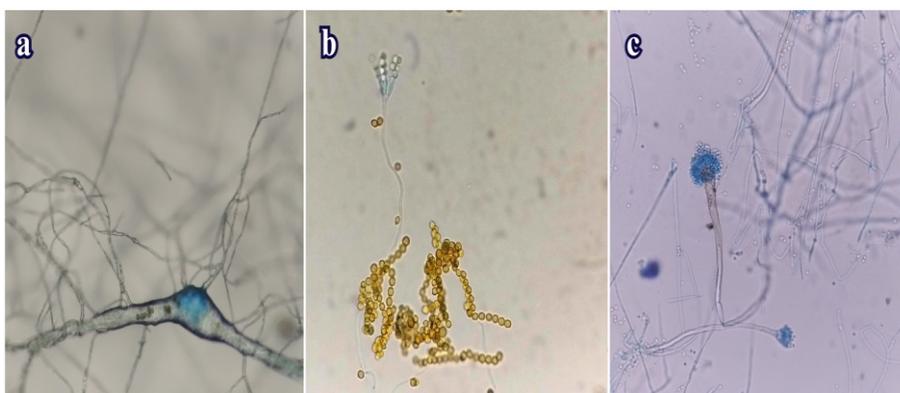
Mold isolation from the plastic wrapping of *Diospyros javanica* leaves resulted in three types of molds. Mold expression on *Diospyros javanica* leaves and mold codes are shown in Table 1.

Table 1. Indigenous mold expressions on *Diospyros javanica* leaves

Number	Macroscopic Expression on Leaves	Cultures
1	White and cottony	DJ1
2	Green and softly-granulated	DJ2
3	Black and roughly-granulated	DJ3

### Fungal Analysis

Microscopic observations of molds grown in slide cultures presented hyphae and conidiospores as presented in Figure 1. Macroscopic and microscopic characteristics of mold isolates were identified with Gandjar *et al.* [14] and several references in order to identify their genus and species names. The macroscopic and microscopic characteristics of each fungi isolated from *Diospyros javanica* leaves are listed in Tables 2 and 3.



**Figure 1.** Microscopic expression of molds grown on slide culture under 400x magnification; Description: (a) DJ1: (b) DJ2, (c) DJ3

Table 2. Macroscopic characteristics of mold cultures grown on PDA medium

Characteristics	Cultures		
	DJ1	DJ2	DJ3
Colony color and texture	White, cottony	Green, soft-granular	Black, rough-granular
Radial Furrow	-	-	-
Concentric	-	Present	Present
Exudate drops	-	-	-

Table 3. Microscopic characterization of mold from *Diospyros javanica* leaves

Characteristics	Cultures		
	DJ1	DJ2	DJ3
Septate/aseptate	Septate	Septate	Septate
Hyphae pigmentation	Hyaline	Dark/dematiceous	Dark/dematiceous
Microscopic form of hyphae	Spiral	Presence of stolon and rhizoid	Presence of foot cells
Asexual spore	-	Conidiospore	Conidiospore
Sexual spore	-	-	-
Cell characteristics	Multicellular and septate	Multicellular and transversely septate	Multicellular and transversely septate

Based on its white cottony colony and minimally differentiated conidiophore (propagule conidiophore), DJ1 was assumed to be from the genus *Humicola*, however the species is yet to be determined [16]. Based on the granular colony texture, DJ2 and DJ3 were determined to belong to the *Aspergillus* genus. The presence of green conidiospore instead of sporangiospore in DJ2 confirms that it isn't the member of *Rhizopus* group. The presence of vialids and metula in DJ3 confirms means that it is and *Aspergillus niger*. The three mold isolates were assumed to be *Humicola* sp. (DJ1), *Aspergillus flavus* (DJ2) and *Aspergillus niger* (DJ3).

#### Plastic Biodegradation Analysis

OD<sub>600nm</sub> of the three spore-suspensions was set to be 0.1 as a standard for all test groups, in order to avoid bias. The results for OD<sub>600nm</sub> obtained for each mold culture are shown in Table 4. Meanwhile, pH measurement of each culture medium was measured at the beginning of incubation (day 0) and at the end of incubation (day 15), and the results are presented in Table 5. In the measurement of the pH of the incubation of the mold culture on the 15th day, all three types of mold showed a decrease in pH. Puspaningrum *et al.* [17] stated that a decrease in pH indicates the presence of metabolic processes by the mold, due to CO<sub>2</sub> buildup. A lower pH in DJ1 may be due to a higher level of growth and metabolism (including extracellular enzymes).

Table 4. OD<sub>600</sub> measurement of spore suspensions of cultures.

OD <sub>600</sub>	Cultures		
	<i>Humicola</i> sp.	<i>Aspergillus flavus</i>	<i>Aspergillus niger</i>
	0.136	0.137	0.103

Table 5. pH measurement of culture media.

Cultures	pH	
	Day 0	Day 15
<i>Humicola</i> sp.	7.5	6.0
<i>Aspergillus flavus</i>	7.5	6.5
<i>Aspergillus niger</i>	7.5	6.5
Control	7.5	7.5

Mold biomass measurements were measured at the final stage of incubation. The results of mold biomass measurements are shown in Table 6. For the biomass measurements, results from each test group

were averaged. The results showed that mold isolate with code DJ1 (*Humicola* sp.) had the largest biomass compared to the other two types of isolates, which was 0.004 g/mL. This suggests that *Humicola* was more adaptable to grow in minimum medium with PE as an alternative carbon source. This evidence also supports the lower pH in *Humicola* after 15 days of incubation, which results from a higher rate of metabolism. To further support the claim of *Humicola* being able to use PE as an alternative carbon source, plastic degradation efficiency was calculated. The results of the percentage of plastic degradation efficiency are shown in Table 7.

Table 6. Average culture biomass after biodegradation assay

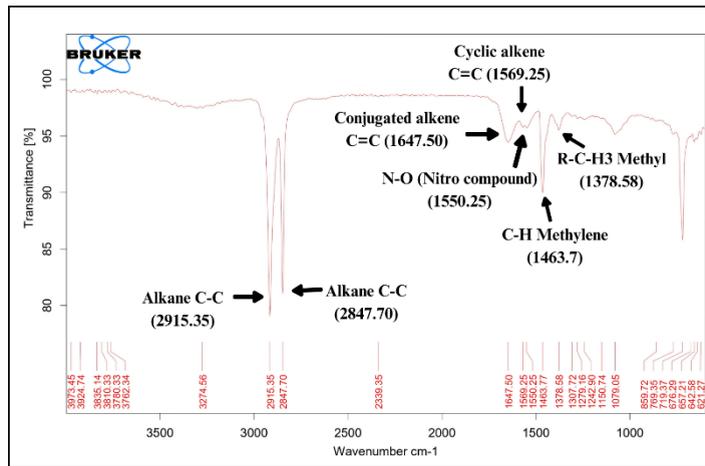
Cultures	Biomass (g/mL)
<i>Humicola</i> sp.	0.004067
<i>Aspergillus flavus</i>	0.000600
<i>Aspergillus niger</i>	0.003033

Table 7. Average degradation efficiency percentage of each culture in biodegradation assay.

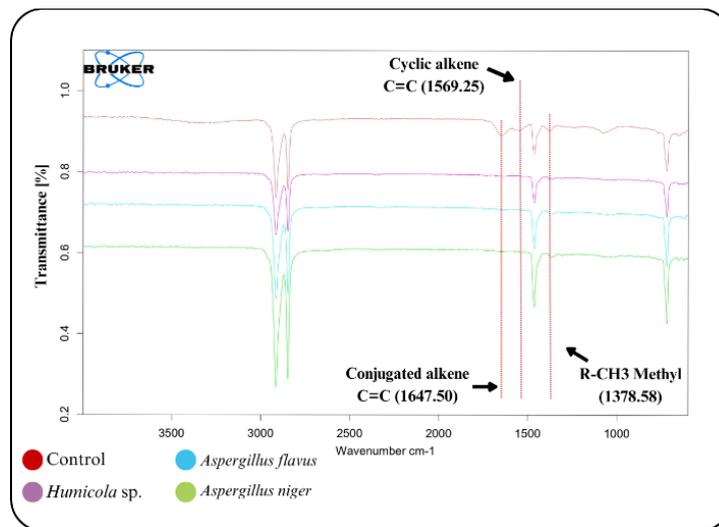
Culture	Efficiency of Plastic Degradation (%)
<i>Humicola</i> sp.	23.96
<i>Aspergillus Flavus</i>	1.87
<i>Aspergillus niger</i>	0.04

*Humicola* sp. has the highest biodegradation efficiency value compared to the *Aspergillus* genus, with a value of 23.96 % as shown in Table 7. The genus *Humicola* has previously been used in an acid-thermoplastic starch-based bio-plastic degradation by Ko *et al.*, yielding 12.2 % degradation respectively after three months of incubation, also being the highest most effective biodegradator in respect to the other subjects [18]. Its cutinase enzymes have also been proven suitable in catalyzing hydrolysis of PET, in an experiment conducted by de Castro *et al.*, being the highest enzyme-catalyzed hydrolysis amount at the time [19]. The *Aspergillus flavus* and *Aspergillus niger* test group yielded low biodegradation percentage, even though the genus *Aspergillus* is well known as a plastic biodegradator, as shown in a review by Nasrabadi *et al.* and Ekanayaka *et al.* [20, 3].

The results of FTIR spectra of plastic samples after biodegradation are displayed in the overlay, between the control and the biodegradation treatment of mold isolates with codes *Humicola* sp., *Aspergillus flavus*, and *Aspergillus niger*. The FTIR characterization of PE sample after 15-days of incubation in control group can be seen in Figure 2, showing the presence of groups such as alkanes (symmetrical and asymmetric C-H stretching), methylene, and methyl, which were similar to the results by Smith *et al.* [21]. FTIR spectra of each test group after 15-days incubation is presented in an overlay (Figure 3). The overlay shows a decrease in the percent transmission at a frequency of 1650-1600  $\text{cm}^{-1}$  on all groups other than the control, which is the response frequency of conjugated alkenes and cyclic alkenes. The decrease in absorbance (sloping of the curve) is more prominent in *Humicola* compared to the other groups. The same case can be seen at a frequency of 1378  $\text{cm}^{-1}$ , which is the response frequency of the methyl group. Based on a statement by Spina *et al.*, the reduction in methyl groups after contact with fungi indicates that biodegradation occurs at the terminal methyl end [7]. PE chain cleavage through C-C bond cleavage has previously been found in other organisms as well, such as in waxworms [22].

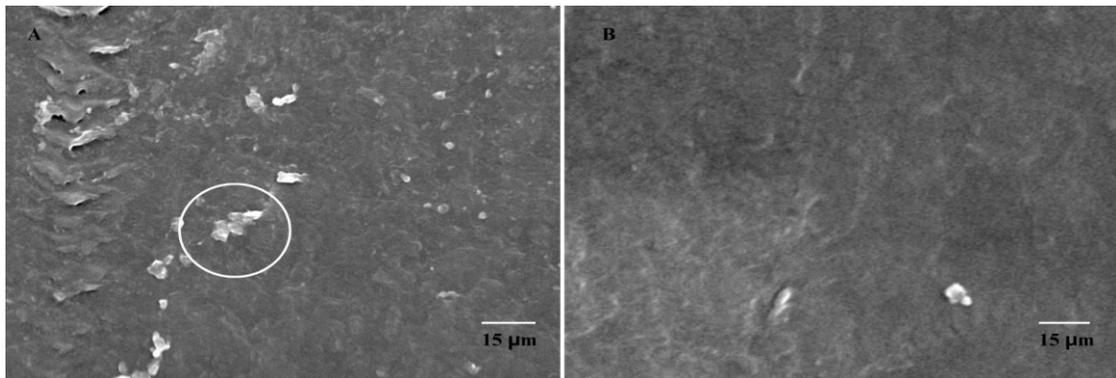


**Figure 2.** FTIR characterization of PE after 15-days incubation in control group.



**Figure 3.** Overlay of FTIR test results on control group, *Humicola* sp., *Aspergillus flavus*, and *Aspergillus niger* after 15-days incubation.

The figure also shows that the peak between the frequencies of  $1600\text{ cm}^{-1}$  and  $1800\text{ cm}^{-1}$ , which is the frequency range at which carbonyl groups are present/respond, decrease in intensity (sloping curve) especially in *Humicola* test group. The decrease in the intensity of the peak in the plastic after the addition of mold indicates a reduction in the carbonyl group in the tested plastic sheet. The decrease in peak intensity is also in accordance with research by Sangale *et al.* [11], where plastic with mold has a smaller peak compared to the control, indicating that there is a decrease in the concentration of carbon groups post-treatment. It is worth noting however, that there seems to be no change in the absorbance at  $2900\text{--}3000\text{ cm}^{-1}$  frequency across test groups, suggesting no change in these alkene chains. This FTIR spectra result supports the previous result in plastic degradation efficiency, where *Humicola* group shows better degradation than *Aspergillus* group.



**Figure 4.** (A) SEM Visualization of a plastic piece after 15 days of incubation with *Humicola*; (B) Plastic piece after 15 days of incubation in plastic control or without treatment under 15,000 $\times$  magnification.

Figure 4 shows the SEM visualizations were performed at a magnification of 15,000 $\times$  or the mold isolate with the highest percentage of degradation efficiency, being *Humicola*, and the control group. In the SEM images of plastic with DJ1, cracks were found, and were suspected to be caused by hyphae attachments. This is in agreement with Sangale *et al.*, where SEM analysis of plastic degradation by mold was indicated by the presence of plastic-surface damage in the form of cracks, peels, or puncture marks [11]. This finding can also be backed by stereo-microscope photographs of the plastics presented in Figure 5, showing the attachments of hyphae on each plastic piece.



**Figure 5.** Stereo-microscope photography of mold presence on plastic sheets in biodegradation assay for DJ1 (*Humicola*), DJ2 (*Aspergillus flavus*), and DJ3 (*Aspergillus niger*), under 150 $\times$  magnification.

Stereo-microcopy results show that all test groups were able to stick to- and penetrate PE pieces. It also shows that *Humicola* has more prominent growth and attachment to the plastic pieces. The visualization by stereo-microscopy helps support the quantitative result in which *Humicola* has a better potential for plastic biodegradation, when compared to other test groups.

## CONCLUSION

As a conclusion, this study successfully obtained three types of mold (*Humicola* sp., *Aspergillus flavus*, and *Aspergillus niger*) isolated from plastic wrappings of *Diospyros javanica* leaves. Those molds have proven to have greater values in the percentage of plastic degradation. The percentage of plastic degradation efficiency from *Humicola* sp. was 23.90 %, *Aspergillus flavus* 1.87%, and *Aspergillus niger* 0.04 %, determined in post-incubation. The percentage of degradation was supported by evidence of increased

biomass, decrease in pH, decreased response of methyl, methylene, and alkene groups on FTIR spectra, and visualization of plastic peeling on SEM test. The outcomes of this study are expected to be further analysed into solutions for environmentally friendly plastic biodegradation, to further help in managing and handling of plastic waste.

Molds isolated from *Diospyros javanica* plastic leave-wrappings have been tested to produce a greater percentage of plastic degradation than some previous studies. The results of this research are expected to be processed into biodegradation products and solutions for environmentally friendly handling of plastic waste. This study recommends conducting further tests, such as enzyme tests, to support data completeness.

## ACKNOWLEDGEMENTS

We would like to express our gratitude for the full support from Direktorat Jenderal Pendidikan Tinggi, Riset, and Teknologi Indonesia (Ditjen Diktiristek), Airlangga University (UNAIR), Faculty of Science and Technology, Department of Biology, for providing facilities and fundings to help complete this bioprospection research.

## AUTHOR'S CONTRIBUTION

All authors conducted research, wrote, and revised the article. Fahmi and Anisa conceptualized the main research idea and provided the theoretical framework. Farra and Fredrick documented each research result. Istiana reminded and provided a schedule for conducting the research. Fahmi designed the research, supervised the progress of the research; Anisa led the review, revision, and approval of the article.

## CONFLICT OF INTEREST STATEMENT

The authors agree that this research was conducted in the absence of any self-benefits, commercial, or financial conflicts and declare absence of conflicting interests with the funders.

## REFERENCES

- [1] Pilapitiya, P.G.C.N.T., and Amila, S.R. (2024). The World of Plastic Waste: A Review. *Clean Materials*, 11, 100220.
- [2] Evode, N., Sarmad, A.Q., Muhammad, B., Damia, B., and Hafiz, M.N.I. (2021). Plastic Waste and Its Management Strategies for Environmental Sustainability. *Case Studies in Chemical and Environmental Engineering*, 4, 100142.
- [3] Ekanayaka, A.H., Saowaluck, T., Donqin, D., Ruifang, X., Nakarin, S., Steven, L.S., Chengjiao, D., and Samantha, C.K. (2022). A Review of Fungi that Degrade Plastic. *Journal of Fungi*, 8 (8): 722.
- [4] Patel, R. M. (2016). Polyethylene. Multilayer Flexible Packaging, 17–34. doi:10.1016/b978-0-323-37100-1.00002-8
- [5] Ziani, K., Ionitã-Mândrican, C.B., Mititelu, M., Neacsu, M.S., Negrei, C., Morosan, E., Drăgănescu, D., Preda, O.T. (2023). Microplastics: A Real Global Threat for Environment and Food Safety: A State of the Art Review. *Nutrients*, 15: 617.
- [6] Wilkes, R.A., and Aristilde, L. (2017). Degradation and Metabolism of Synthetic Plastics and Associated Products by *Pseudomonas* sp.: Capabilities and Challenges. *Journal of Applied Microbiology*, 123(3), 582-593.
- [7] Spina, F., Tummino, M.L., Poli, A., Prigione, V., Ilieva, V., Cocconcelli, P., Puglisi, E., Bracco, P., Zanetti, M., and Varese, G.C. (2021). Low Density Polyethylene Degradation by Filamentous Fungi. *Environmental Pollution*, 274, 116548.

- [8] Muhonja, C.N., Makonde, H., Magoma, G., and Imbuga, M. (2018). Biodegradability of Polyethylene by Bacteria and Fungi from Anddora Dumpsite Nairobi Kenya. *PLOS ONE*, 13.7: e0198446.
- [9] Sanchez, C. (2020). Fungal Potential for the Degradation of Petroleum-based Polymers: An Overview of Macro and Biodegradation. *Biotechnology Advances*, 40, 107501
- [10] Pathak, V.M., and Navneet. (2017). Review on the Current Status of Polymer Degradation: A Microbial Approach. *Bioresources and Bioprocessing*, 4, 15.
- [11] Sangale, M.K, Shahnawaz, M., and Ade, A.B. (2019). A Review on Biodegradation of Polythene: The Microbial Approach. *Journal of Bioremediation and Biodegradation*, 3 (10), 1-9.
- [12] Rohmah, U.M., Shovitri, M., and Kuswytasari. (2019). Degradasi Plastik oleh Jamur *Aspergillus terreus* (LM 1021) pada pH 5 and 6; serta Suhu 25°C and 35°C. *Jurnal Sains and Seni ITS*. 7(2), 60-65.
- [13] El-Morsy, E.M., Hassan, H.M., and Ahmed, E. (2017). Biodegradative Activities of Fungal Isolates from Plastic Contaminated Soils. *Mycosphere*, 8(8): pp. 1071-1087.
- [14] Gandjar, I., Robert, A.S., Karin, v.d.T.V., Ariyanti, O., and Iman, S. (1999). *Pengenalan Kapang Tropik Umum*, First Edition. Jakarta: Yayasan Obor Indonesia.
- [15] Malachová, K., Novotný, Č., Adamus, G., Lotti, N., Rybková, Z., Soccio, M., Cíková, P.S., Verney, V. and Fava, F. (2020). Ability of *Trichoderma hamatum* Isolated from Plastics-Polluted Environments to Attack Petroleum-Based, Synthetic Polymer Films. *Processes*, 8 (4), 467.
- [16] Wang, X.W., Yang, F.Y., Meijer, M., Kraak, B., Sun, B.D., Jiang, Y.L., Wu, Y.M., Bai, F.Y., Seifert, K.A., Crous, P.W., Samson, R.A., Houbraken, J. (2019). Redefining *Humicola Sensu Stricto* and Related Genera in the *Chaetomiaceae*. *Studies in Mycology*, 93: 65-153.
- [17] Puspaningrum, D.H.D., Ni Luh, U.S., and Ni Kadek, Y.S. (2022). Karakteristik Kimia and Aktivitas Antioksidan selama Fermentasi *Kombucha cascara* Kopi Arabika (*Coffea arabika* L.) Desa Catur Kabupaten Bangli. *Jurnal Sains and EdukasiSains*, 5(2), 44-51.
- [18] Ko, Y., Youri, Y., Dockyu, K., Yong, H.L., Sunil, G., and Hor-Gil, H. (2024). Fungal Biodegradation of Poly (butylene adipate-co-terephthalate)-polylactic Acid-thermoplastic Starch Based Commercial Bio-plastic Film at Ambient Conditions. *Chemosphere*, 353, 141554.
- [19] De Castro, A.M., Adriano, C., Diego, S., Luiz, S.C.J., Hercilio, d.A.H., and Sonia, M.C.d.M. (2019). High-fold Improvement of Assorted Post-consumer Poly (Ethylene Terephthalate) (PET) Packages Hydrolysis Using *Humicola insolens* Cutinase as a Single Biocatalyst. *Process Biochemistry*, 81, 85-91.
- [20] Nasrabadi, A.E., Bahman, R., and Ziaeddin, B. (2023). Recent Progress in Biodegradation of Microplastics by *Aspergillus* sp. in Aquatic Environments. *Colloid and Interface Science Communications*, 57, 100754.
- [21] Smith, B.C. (2021). The Infrared Spectra of Polymers II: Polyethylene. *Spectroscopy*, 36 (9), 24-29.
- [22] Kundungal, H., Gangarapu, M., Sarangapani, S., Patchaiyappan, A., and Devipriya, S.P. (2019). Role of Pretreatment and Evidence for the Enhanced Biodegradation and Mineralization of Low-density Polyethylene Films by Greater Waxworm. *Environmental Technology*, 42 (5), 717-730.