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Isolation and Identification of Gut Bacteria from Mealworm (*Tenebrio molitor*) with Potential for Microplastic Degradation

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Abstract

Background: *Plastic that accumulates in the environment over extended periods can fragment into smaller particles known as microplastics. The uncontrolled buildup of microplastics poses significant risks, including harmful health effects on living organisms and negative impacts on ecosystems. One promising sustainable solution under investigation is the use of gut bacteria from mealworm (Tenebrio molitor) for plastic biodegradation. This study aims to identify the gut bacterial species involved in degrading plastics ingested by mealworm fed with Polystyrene (PS), Polyethylene (PE), and Polyethylene Terephthalate (PET), and to evaluate the degradation rate exhibited by these bacteria.* **Methodology:** *Bacterial isolation was carried out from the gut of mealworm that were fed plastic for 30 days, using Mineral Salts Medium (MSM) as a selective medium, followed by testing the plastic degradation potential of the isolated gut bacteria. The microbial species involved were identified using the VITEX-2 Compact System.* **Findings:** *Bacteria isolated from the digestive tract of mealworm showed significant potential in degrading plastics. Pseudomonas aeruginosa was found in PS and PE treatments with degradation rates of 14.4% and 44.4%, respectively, while Aeromonas salmonicida was identified in the PET treatment with a degradation rate of 16.3%.* **Contribution:** *These findings highlight the role of mealworm gut microbes in degrading PS, PE, and PET, supporting their potential as eco-friendly biodegradation agents*

Keywords: *Biodegradation; Gut Bacteria; Microplastics; Tenebrio molitor*

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INTRODUCTION

Plastic is a fundamental material in daily human life, particularly in the packaging of food and beverages (Hartono & Rachmat, 2022). The widespread use of plastic has directly contributed to the growing accumulation of plastic waste in the environment. According to the Ministry of Environment and Forestry, Indonesia generated 175,000 tons of waste daily in 2019, amounting to approximately 64 million tons annually (Aromi et al., 2024). However, only about 9-18% of the total plastic waste is effectively recycled, with the majority either incinerated, disposed of in landfills, or left to pollute the environment (Guerrero & Guerrero, 2023).

The persistent rise in plastic waste accumulation is primarily linked to the widespread utilization of plastic variants such as *Polyethylene Terephthalate* (PET), *Polyethylene* (PE), and *Polystyrene* (PS). PET is extensively employed in the production of bottled water packaging. Based on data from the South African Plastic Recycling Organization, nearly 90 % of plastic bottle waste is ultimately discarded into landfills. This situation is compounded by the fact that many manufacturers remain hesitant to adopt recycling practices due to the lower cost of producing virgin plastic compared to recycled materials (Olatayo et al., 2021). PE, a polymer synthesized from ethylene, is commonly found in packaging applications, particularly in everyday items such as shopping bags. Meanwhile, PS is widely used in the manufacture of single-use food containers (Arwini, 2022). The growing prevalence of online shopping and food delivery services has contributed to the increased demand for PS based packaging (Matyja et al., 2020).

Plastic waste discarded into the environment undergoes physical changes over time due to natural degradation processes (Napper & Thompson, 2019). As degradation progresses, plastic fragments develop surface cracks, discoloration, and eventually break down into microparticles measuring less than 5 mm, known as microplastics (Pironti et al., 2021). Because of their minute size, microplastics disperse easily and contaminate various environmental compartments, including water, soil, and air (Luqman et al., 2021). Their presence poses significant ecological threats. In terrestrial ecosystems, microplastics can alter soil physical properties by reducing bulk density, impairing water retention capacity, and disrupting the activity of soil microorganisms (MacHado et al., 2018).

In aquatic ecosystems, microplastics are often ingested by aquatic organisms due to their size similarity to plankton (Zuo et al., 2020). The ingestion of these particles can cause digestive tract harm, reduced growth rates, inhibition of enzymatic activity, disruption of steroid hormone levels, reproductive impairments, and exposure to toxic additives associated with plastic materials (Labibah & Triajie, 2020). The accumulation of microplastics in aquatic organisms also poses risks to human health through the food chain, particularly via the consumption of seafood such as fish and shellfish (Jamika et al., 2023).

Microplastics ingested by the human body can induce alterations in the gut microbiome, leading to an imbalance between beneficial and harmful bacteria. This imbalance can result in various digestive symptoms such as abdominal discomfort, bloating, and changes in bowel habits (Lee et al., 2023). Beyond their physical impact on the digestive system, microplastics also pose chemical toxicity risks through the

absorption and accumulation of environmental toxins, including *Polychlorinated Biphenyls* (PCBs), *metals*, and *Polybrominated Diphenyl Ethers* (PBDEs). The accumulation of these substances in the human body can be detrimental to health (Jamika et al., 2023).

Owing to the environmental and health impacts of microplastics, one promising solution is biodegradation, a process involving chemical breakdown by microorganisms, particularly bacteria. These bacteria possess the ability to degrade various organic pollutants into harmless compounds, making them a potential tool for addressing microplastic contamination (Riandi et al., 2017). One such potential source of plastic-degrading bacteria is the digestive tract of mealworm (*Tenebrio molitor*).

Mealworm have been recognized for their ability to consume and degrade various types of plastic, including PS, PE, and PET (Oktari et al., 2023; Pinchi et al., 2022). This capability is closely linked to the bacterial community residing in their digestive system. Numerous studies have successfully isolated bacteria from the digestive tract of mealworm that exhibit potential for plastic degradation. Such is the case of Pascagaza et al., (2020) identified several bacterial species from the digestive tract of mealworms fed with PS, such as *Bacillus anthracis*, *Stenotrophomonas* sp., *Bacillus* sp., *Pantoea agglomerans*, *Erwinia persicina*. Similarly, Octavia et al., (2023) identified other bacterial genera including *Corynebacterium*, *Enterococcus*, *Lactococcus*, *Pediococcus*, *Brevibacillus*, *Spiroplasma*, *Lactobacillus*, *Vagococcus*, and *Weissella* in mealworms treated with PE plastic. These findings support the potential role of gut-associated bacteria in the biodegradation of synthetic polymers. Furthermore, utilizing these bacteria presents a promising opportunity to develop bacterial consortia that synergistically enhance plastic degradation efficiency under natural environmental conditions (Dharmasiddhi et al., 2025).

Although there have been several previous studies, the research on bacterial diversity in the digestive tract of local mealworm is still limited. This study aims to identify the bacteria present in the digestive tract of mealworm after treatment with PE, PS, and PET plastics, and to determine the rate of plastic degradation by these bacteria. The results of this study are expected to contribute scientifically to the utilization of bacteria from the digestive tract of local mealworms as biological agents for plastic decomposition.

METHOD

Material

The raw materials used in this study included *Mineral Salt Medium* (MSM), which was employed to ensure that plastic served as the sole carbon source for bacterial growth (Ali et al., 2023); *Nutrient Agar* (NA), which was used for obtaining pure bacterial isolates (Bhalsing & Jawale, 2021); and *Nutrient Broth* (NB), which was utilized for bacterial culture recovery (Jain & Tiwari, 2015). The types of plastic used were PS (*Polystyrene*), PET (*Polyethylene terephthalate*), and PE (*Polyethylene*), all of which were purchased from an e-commerce platform (Shopee). The mealworms (*Tenebrio molitor*) used in this study were obtained from a bird feed shop located on Tanjung Senang, Bandar Lampung, and were approximately one month old.

Extraction of the Digestive System

10 mealworms from each treatment group were selected for isolation of their gut bacteria. The caterpillars were thoroughly rinsed with distilled water to remove any external debris attached to their bodies. The caterpillars were sterilized by immersing them in 100 mL of 70 % alcohol for about 1 minutes. This step ensures the removal of potential surface contaminants and minimizes the risk of external microbial contamination.

The mealworms are mechanically homogenized using a pestle and mortar. The mealworms are crushed into a fine powder, resulting in a homogenized mixture suitable for isolation of gut bacteria. Gut bacteria from the mealworms were carefully extracted from the homogenate to be cultured and identified as bacteria capable of breaking down plastic. This meticulous procedure ensures that the isolated microorganisms are exclusively derived from gut bacteria, with no contamination from external sources.

Isolation of the Digestive System

The crushed samples of the mealworms gut were placed in a test tube and diluted to a concentration of 10^{-9}. The diluted samples were then inoculated into MSM using the pour plate method (Istiqomah, 2020), with the addition of 0.1 grams each of PS, PE, and PET plastic powder. The cultures were incubated for 20 day under aerobic conditions and without additional light exposure. After the incubation period, the bacterial isolates that grew were purified using the streak plate method on NA (Riandi et al., 2017).

A single colony obtained from the purification step was then selected and used for testing its ability to degrade plastic. This process ensured the isolation of specific bacteria capable of plastic degradation while maintaining accuracy and consistency in the experimental procedures at 37 °C (Wati et al., 2021).

Preparation of Plastic

The PS, PE, and PET plastics were cut into pieces measuring 1 x 1 cm and sterilized by soaking them in 70 % alcohol for 30 minutes (Rohmah et al., 2019). Following sterilization, the samples were rinsed with distilled water and exposed to UV light in a Laminar Air Flow cabinet for 30 minutes to ensure further sterilization. To determine the initial dry weight of the plastics, the pieces were dried in an oven at 80 °C for 12 hours to remove any moisture content, allowing for the accurate measurement of the pure weight of the plastics. After the drying process, samples were weighed to determine their initial weight (Riandi et al., 2017). This initial measurement ensured accuracy and served as a baseline for subsequent degradation analysis. All treatments were conducted in triplicate to represent actual conditions, reduce experimental errors, and ensure analytical validity.

Plastic Degradation

Total of 1 mL of bacterial culture was inoculated into 10 mL of NB, and then incubated for 18 hours at room temperature using a shaker at a speed of 150 rpm refers to Istiqomah (2020). After incubation, 0.5 mL of the inoculum was taken and

inoculated into 10 mL of MSM broth media. Previously prepared plastic pieces were then added to the culture media containing isolated bacteria and incubated for 30 days at a temperature of 37 °C (Wati et al., 2021). As a control, plastic that had been pretreated was placed into MSM broth media without the addition of bacterial isolates (Istiqomah, 2020).

After the biodegradation incubation period is complete, the plastic pieces are retrieved using sterile tweezers and washed with distilled water. Subsequently, the plastic is sterilized with 70% alcohol and air-dried. The plastic pieces are then dried in an oven at 80°C for 12 hours, cooled in a desiccator for 24 hours, and then dry weight measurement is conducted (Rohmah et al., 2019).

Identification of Bacteria

The identification of bacteria is carried out through the observation of macroscopic and microscopic characteristics of the isolates that have successfully grown. Macroscopic observation includes evaluating the morphological characteristics of colonies on solid media, such as shape, size, edges, and color of the colonies (Fatti et al., 2025; Wati et al., 2021). Meanwhile, microscopic observation is performed through Gram staining by applying crystal violet solution, iodine, 96% alcohol, and safranin (Istiqomah, 2020). This identification process refers to *Bergey's Manual of Determinative Bacteriology Seventh Edition* (Breed et al., 1957), *Bergey's Manual of Systematic Bacteriology Second Edition Volume Two* (Brenner et al., 2005), *Bergey's Manual of Systematic Bacteriology Second Edition Volume Three* (Vos et al., 2011), and supported by various references from scientific articles.

Bacteria are identified using the automatic instrument VITEX-2 Compact System, which operates based on determining the MIC (Minimum Inhibitory Concentration) as a standard reference for finding species with a barcode, accompanied by an ID card down to the lowest level, and utilizing the Advanced Expert System (AES) software. The ID card is placed into a tube containing 3 mL of 0.45 % NaCl solution and the bacterial isolate to be identified, and then incubated for 24 hours. Once completed, the results can be automatically printed with data validation and result interpretation similar to conventional biochemical testing (Vianti et al., 2020).

Data Analysis

After all stages are completed, proceed to data analysis by calculating the percentage of plastic weight loss. The formula for calculating the percentage of plastic weight loss refers to Riandi et al., (2017) as follows.

$$Degradation\ (\%) = \left(\frac{wi - wf}{wi}\right) x\ 100\%$$

Note:
wi : Initial weight of the plastic (before degradation)
wf : Final weight of the plastic (after degradation period)

The estimated total degradation time was calculated using the ratio between the initial plastic weight and the degraded weight after 30 days. Reference weights used in this study were 10 g for PS (*Polystyrene*), 6 g for PE (*Polyethylene*), and 40 g for PET (*Polyethylene Terephthalate*). The formula applied was: (by author)

$$T = \frac{\left(\frac{W_o}{W_d} x\ 30\right)}{365}$$

Note:
T : Estimated total degradation time (years)
W_0 : Initial plastic weight (g)
W_d : Degraded plastic weight after 30 days (g)

RESULT AND DISCUSSION

Identification and Characterization of Gut Bacteria from Mealworm

Nine bacterial isolates were successfully obtained from the digestive tract of mealworms that were given different treatments. Each isolate was coded based on the type of treatment, namely PS (*Polystyrene*), PE (*Polyethylene*), and PET (*Polyethylene Terephthalate*), with each replicate. The detailed information regarding these isolates is provided in Table 1 below.

Table 1. Bacterial codes from isolation of the gut bacteria

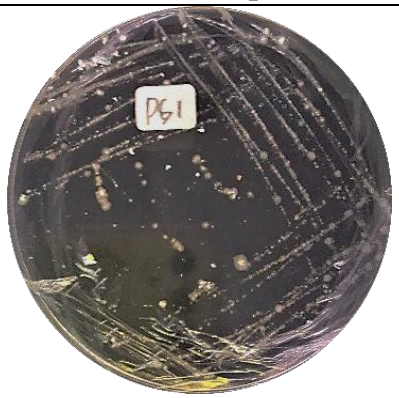
PS (*Polystyrene*)	PE (*Polyethylene*)	PET (*Polyethylene Terephthalate*)
PS1	PE1	PET1
PS2	PE2	PET2
PS3	PE3	PET3

The characterization of bacteria was carried out by observing the colony morphology and Gram staining to obtain an initial picture of the identity of the isolated bacteria. This process refers to *Bergey's Manual of Determinative Bacteriology Seventh Edition* (Breed et al., 1957), *Bergey's Manual of Systematic Bacteriology Second Edition Volume Two* (Brenner et al., 2005) and *Bergey's Manual of Systematic Bacteriology Second Edition Volume Three* (Vos et al., 2011). In addition, several supporting articles were also used as additional references to strengthen the initial identification process.

The results of the bacterial colony morphology characterization are presented in Table 2, which contains detailed information regarding the shape, color, size, and edge of the colonies from each bacterial isolate successfully obtained. Furthermore, the results of Gram staining are shown in Table 3, which provide an overview of the bacterial cell morphology and help distinguish between Gram-positive and Gram-negative bacteria. Microscopic observations of the bacterial cells during the Gram staining process were conducted at 100x magnification, thereby facilitating a more

detailed identification of cellular morphological characteristics and supporting the preliminary analysis to determine the bacterial identity.

Table 2. Macroscopic characteristic of bacterial isolates

Isolate code	Macroscopic	Description
PS 1		Macroscopic colonies are round-shaped, the colony edges appear flat, with a medium to small size and white to cream color.
PS 2		Macroscopic colonies are round-shaped, the colony edges appear flat, with a medium to small size and white to cream color.
PS 3		Macroscopic colonies are round-shaped, with flat edges, medium-sized colonies, and cream-colored.

Isolate code	Macroscopic	Description
PE 1		Macroscopic colonies are round-shaped, the colony edges appear smooth, with a medium to small size and white to cream color.
PE 2		Macroscopic colonies are round in shape, with smooth colony edges, small to medium-sized colonies, and a cream-yellow color.
PE 3		Macroscopic colonies are round in shape, with flat edges, medium to small in size, and cream-yellow in color.
PET 1		Macroscopic colonies are round-shaped, the colony edges appear flat, with a medium to small size and white to cream color.

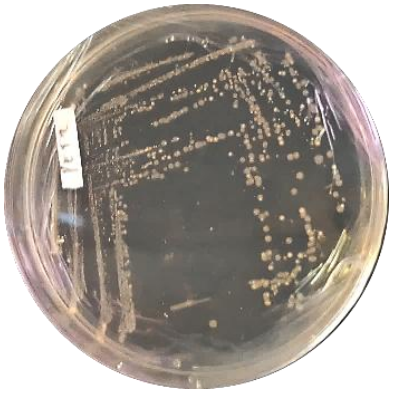
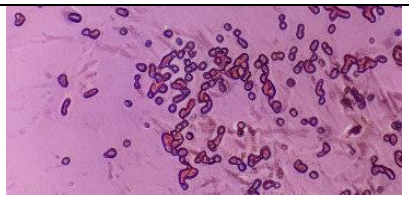
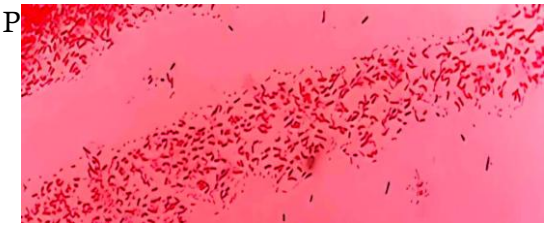
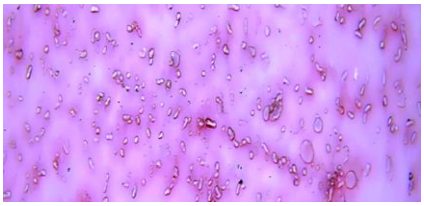
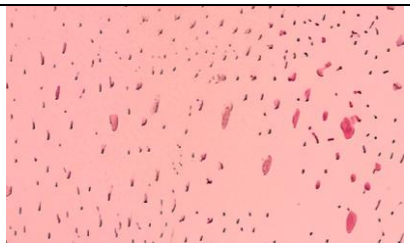
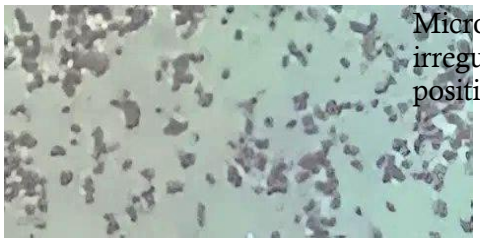
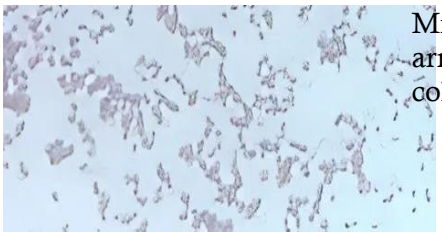
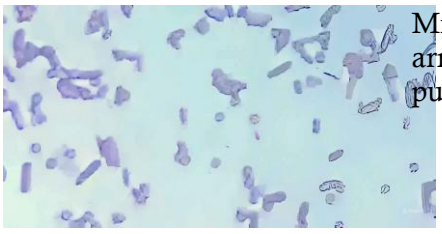
Isolate code	Macroscopic	Description
PET 2		Macroscopically, the colonies are round in shape, the edges of the colonies appear smooth, the colony size is small, and the colony color is cream-yellow.
PET 3		Macroscopic colonies are round in shape, with irregular edges, small in size, and white in color.

Table 3. Microscopic characteristics of bacterial isolates at 100× magnification

Isolate code	Microscopic	Description
PS 1		Microscopic colonies are round and clustered like grapes, purple in color and gram-positive.
P		Microscopic colonies are straight rod-shaped, either paired or single, red in color and gram-negative in nature.
PS 3		Microscopic colonies are single straight rod-shaped, red in color, and are gram-negative.

Isolate code	Microscopic	Description
PE 1		Microscopic colonies are straight rod-shaped, either paired or single, red in color and gram-negative in nature.
PE 2		Microscopic colonies are short rod-shaped paired, purple in color, and gram-positive in nature.
PE 3		Microscopic colonies are round and irregular, purple in color and gram-positive.
PET 1		Microscopic colonies are straight rod-shaped, either paired or single, red in color and gram-negative in nature.
PET 2		Microscopic colonies are round and arranged in short chains, purple in color, and are gram-positive.
PET 3		Microscopic colonies are rod-shaped, arranged as single units or in pairs, purple in color, and gram positive.

Based on Table 2, isolate PS1 exhibited morphological characteristics consistent with *Staphylococcus* sp. Colonies were round with smooth edges, medium to small in size, and exhibited white to cream coloration. Microscopic examination revealed spherical cells arranged in clusters resembling grape-like formations. The cells stained purple, indicating a Gram-positive classification. The retention of the crystal violet

stain is attributed to the thick peptidoglycan layer in the bacterial cell wall (Purnamasari et al., 2023; Zendejas et al., 2014; Public Health England, 2015b).

Meanwhile, isolates PS2 and PE1 demonstrated morphological and microscopic features resembling *Pseudomonas* sp. Colonies were round with flat edges, medium to small in size, and exhibited a white to cream color. Microscopic analysis revealed straight rod-shaped cells arranged singly or in pairs, stained red, and classified as Gram-negative (Su et al., 2018; Chaudhury et al., 2018). *Pseudomonas* sp. are known to produce a variety of enzymes involved in plastic degradation, including *Serine Hydrolase* (SH), *Esterase* (Agarwal et al., 2024), *PETase* (Howard et al., 2025), and *Alkane Hydroxylase* (Atanasova et al., 2021). These enzymes play a key role in enhancing the hydrophilicity of plastic surfaces by converting them from hydrophobic to more water-permeable states, thereby facilitating and accelerating the degradation process (Santo et al., 2013; Jeon & Kim, 2015; Przemieniecki et al., 2020; Wei & Zimmermann, 2017).

The PS3 isolate exhibited phenotypic characteristics consistent with *Enterobacter* sp. Colonies were round with flat edges, of medium size, and cream in color. Microscopic observation revealed single, straight, rod-shaped cells appearing red under Gram staining, indicating that the isolate is Gram-negative (Mahgoub et al., 2023; Shahab et al., 2017). Similarly, the PE2 isolate demonstrated morphological features resembling those of *Exiguobacterium* sp. The colonies were round with flat edges, ranging from small to medium in size, and displayed a yellowish cream coloration. Microscopically, the cells appeared as short paired rods, stained purple, and were classified as Gram-positive (Devi et al., 2024; Rodrigues et al., 2006; Tedesco et al., 2021).

The PE3 isolate showed similarities to *Micrococcus* sp., with colonies that were round, had flat edges, and were medium to small in size, with cream to yellowish pigmentation. Microscopic examination revealed irregularly round cells, purple in color, and classified as Gram-positive (Lubitz et al., 2002; Nwachukwu et al., 2019; Shi et al., 2023; Devi et al., 2024; Public Health England, 2015b). The PET1 isolate exhibited morphological characteristics similar to those of *Aeromonas* species. Colonies were round with flat edges, medium to small in size, and displayed a white to cream coloration. Microscopically, the cells were observed as straight rods, occurring singly or in pairs, stained red, and classified as Gram-negative (Nahar et al., 2016). This bacterium is known for its ability to produce several extracellular enzymes, including *lipase* (Yi et al., 2022), *lignin peroxidase*, and *laccase* (Bharagava et al., 2018). These enzymes are capable of catalyzing various chemical reactions, notably the depolymerization of polyesters such as polylactic acid and the hydrolysis of oligomers (Carniel et al., 2017; Danso et al., 2019).

The PET2 isolate exhibited macroscopic characteristics consistent with *Enterococcus* sp., forming round colonies with flat edges, small in size, and cream to yellowish in color. Microscopically, the cells appeared spherical, arranged in short chains, stained purple, and were identified as Gram-positive (Růžičková et al., 2020; Public Health England, 2015a). In contrast, the PET3 isolate displayed phenotypic traits resembling those of *Bacillus* sp. Colonies were round with irregular edges, small in size, and white in color. Microscopic analysis revealed rod-shaped

cells arranged singly or in pairs, stained purple, and classified as Gram-positive (Sulistiyani et al., 2021; Saputra et al., 2024; Gireesha et al., 2023; Sumardi et al., 2021). *Bacillus* sp. are known for producing *esterase* (Atanasova et al., 2021) and *laccase* (Xue et al., 2025), enzymes that play important roles in plastic degradation.

These results are consistent with previous studies indicating that the digestive tract of mealworms contains a variety of bacteria with the potential to degrade plastics. Pascagaza et al., (2020), for example, identified several bacterial species from the gut of mealworms fed with polystyrene (PS), including *Bacillus anthracis*, *Stenotrophomonas* sp., *Bacillus* sp., *Pantoea agglomerans*, *Erwinia persicina*, and other *Bacillus* strains. Similarly, Octavia et al., (2023) identified bacterial genera such as *Corynebacterium*, *Enterococcus*, *Lactococcus*, *Pediococcus*, *Brevibacillus*, *Spiroplasma*, *Lactobacillus*, *Vagococcus*, and *Weissella* from mealworms that had been exposed to PE.

Although the current study relied on basic macroscopic and microscopic observations for bacterial identification, the range of isolates found still reflects the microbial diversity present in the mealworm gut, which may play a role in the plastic degradation process.

Mealworms Gut Bacteria and Plastic Degradation Ability

The plastic degradation ability of each bacterial isolate is presented in Table 4. This was assessed by measuring the percentage of plastic weight loss after a 30-day incubation period.

Table 4. Plastic mass reduction by bacteria

Isolate Code	Replication	Initial weight (g)	Final weight (g)	Degradation	Average	Percentage (%)
PET1	1	0.034	0.028	0.176	0.163	16.3
	2	0.031	0.025	0.193		
	3	0.033	0.029	0.121		
PET2	1	0.034	0.029	0.147	0.118	11.8
	2	0.030	0.027	0.100		
	3	0.028	0.025	0.107		
PET3	1	0.031	0.028	0.096	0.086	8.6
	2	0.031	0.028	0.096		
	3	0.031	0.029	0.064		
PS1	1	0.019	0.018	0.052	0.084	8.4
	2	0.021	0.019	0.095		
	3	0.019	0.017	0.105		
PS2	1	0.019	0.018	0.052	0.144	14.4

	2	0.021	0.017	0.190		
	3	0.021	0.017	0.190		
PS3	1	0.020	0.019	0.050	0.033	3.3
	2	0.020	0.019	0.050		
	3	0.020	0.020	0.000		
PE1	1	0.006	0.003	0.500	0.444	44.4
	2	0.006	0.003	0.500		
	3	0.006	0.004	0.333		
PE2	1	0.006	0.004	0.333	0.277	27.7
	2	0.006	0.004	0.333		
	3	0.006	0.005	0.166		
PE3	1	0.006	0.005	0.166	0.166	16.6
	2	0.006	0.005	0.166		
	3	0.006	0.005	0.166		

Based on the table 4 above, isolate PE1 exhibited the highest degradation rate at 44.4 %, followed by isolate PS2 with a degradation rate of 14.4 %. Identification using the VITEK-2 Compact System revealed that both isolates are *Pseudomonas aeruginosa*. These results are consistent with the study by Lee et al., (2020), which demonstrated that *P. aeruginosa* can degrade PE at a rate of 0.64 % per day, while PS degrades at a much lower rate of 0.098 % per day. This suggests that *P. aeruginosa* is more effective at degrading PE-type plastics compared to PS. The lower degradation efficiency of PS is likely due to its chemical structure, which contains aromatic rings that require a more complex enzymatic process for breakdown (Yoshida et al., 2016; Palm et al., 2019).

P. aeruginosa is well-known for its notable potential to degrade various types of plastics. This bacterium produces enzymes that contribute to the breakdown of plastic polymers. Among the plastics reported to be degraded by *P. aeruginosa* are *Polypropylene* (PP) (Lee et al., 2020), *Polyvinyl Chloride* (PVC), *Polyvinyl Alcohol* (PVA) (Uwanta et al., 2023), *Poly* (*lactic acid*) (PLA), and *Organically Modified Montmorillonite* (OMMT) (Shimpi et al., 2012). These capabilities position *P. aeruginosa* as a promising candidate for biological biodegradation of plastic waste, especially in efforts to mitigate environmental pollution caused by plastics.

The PET1 isolate was successfully identified as *Aeromonas salmonicida*, exhibiting a degradation rate of 16.3 %, which highlights its potential for plastic degradation. Previous studies have also reported that species within the genus *Aeromonas* can degrade bioplastics such as *Poly-β-hydroxybutyrate*, as well as synthetic compounds like *Bisphenol A* (Gulnaz & Dincer, 2009). This ability indicates that *Aeromonas* holds promise as an effective biodegradation agent for managing plastic waste in the environment.

Variations in plastic degradation levels by microorganisms are generally attributed to differences in the enzymatic activities produced during the biodegradation process. Enzymes such as *Serine Hydrolase* (SH), *Esterase*, *PETase*, *Alkane Hydroxylase*, *Lipase*, *Lignin Peroxidase*, and *Laccase* play crucial roles in breaking down the chemical bonds within plastic polymers into simpler molecules that are easier to metabolize. The efficiency of these enzymes is influenced by the chemical structure and physical properties of plastics such as crystallinity, fusion temperature, and density as well as surface characteristics like hydrophobicity and roughness, all of which can affect the degradation rate. Additionally, differences in enzyme composition and expression levels among microorganisms also determine how quickly and effectively degradation occurs. Thus, enzyme activity specific to certain plastic types is a key factor in the overall efficiency of plastic biodegradation in the environment (Rosato et al., 2022).

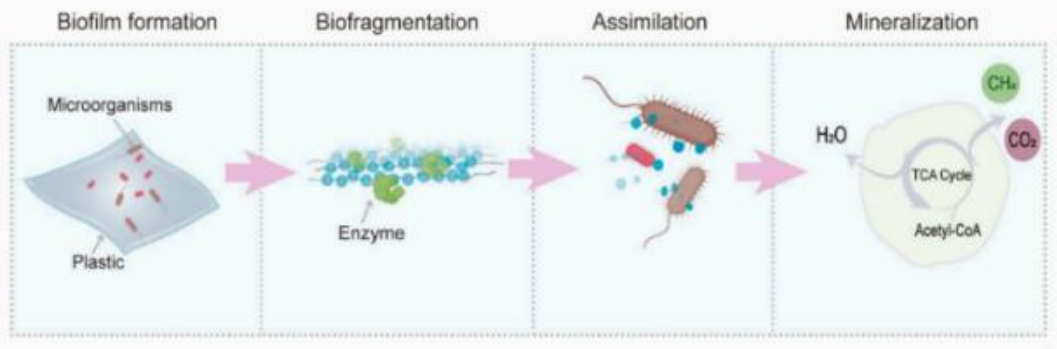


Figure 1. The mechanism of plastic degradation by bacteria (Lv et al., 2024)

The plastic degradation process by microorganisms occurs through several stages: biodeterioration, biofragmentation, assimilation, and mineralization (Lv et al., 2024). During the first stage, biodeterioration, plastic-degrading microorganisms attach to the plastic surface and form a biofilm. This leads to damage of the plastic, marked by the formation of carbonyl groups due to the activity of oxidative enzymes produced by the microorganisms. Further oxidation converts these carbonyl groups into carboxylic acids, which weakens the plastic's structural integrity.

Table 5. Estimated plastic completely degraded by bacteria

No.	Isolate code	Natural degradation (Year)	Degradation by bacteria over 30 days (%)	Estimated Expiry (Year)	Types of bacteria
1.	PET1	450	16.3%	20.16	*Aeromonas* sp.
	PET2		11.8%	27.8	*Enterococcus* sp.
	PET3		8.6%	38.2	*Bacillus* sp.
2.	PE1	10-600	44.4%	1.1	*Pseudomonas* sp.
	PE2		27.7%	1.8	*Exiguobacterium* sp.
	PE3		16.6%	3	*Micrococcus* sp.
3.	PS1	50-80	8.4%	9.8	*Staphylococcus* sp.
	PS2		14.4%	5.7	*Pseudomonas* sp.
	PS3		3.3%	24.9	*Enterobacter* sp.

In the subsequent biofragmentation stage, enzymes secreted by the microorganisms break down the long polymer chains of plastics into smaller compounds through hydrolysis or fragmentation mechanisms. These smaller fragments then enter the assimilation stage, where they are absorbed by bacterial cells and used as sources of carbon and energy. Finally, during mineralization, the metabolites are converted into end products such as *Carbon dioxide* (CO_2), *methane* (CH_4), and *water* (H_2O), which are then released into the environment (Mohanan et al., 2020).

Based on the table 5 above, PET (*Polyethylene Terephthalate)* plastic naturally degrades over approximately 450 years; however, with the assistance of bacteria from the gut of mealworms, its estimated degradation time can be shortened to around 20.16 to 38.2 years. PE (*Polyethylene*), which typically takes between 10 and 600 years to degrade naturally, can have its degradation accelerated by bacteria to approximately 1.1 to 3 years. Meanwhile, PS (*Polystyrene*), which naturally degrades within 50 to 80 years, can be broken down in only about 9.8 to 24.9 years with the help of these bacteria.

These findings indicate that bacteria play a significant role in accelerating the plastic degradation process. The ability of bacteria to modify the structural and physical properties of plastics, such as reducing material strength and increasing water absorption, makes plastics more susceptible to breakdown (Mohanan et al., 2020). Therefore, the application of bacteria as biodegradation agents represents an environmentally friendly solution to address the growing problem of plastic pollution.

CONCLUSION

Plastic waste that persists in the environment for extended periods can degrade into microplastics, posing serious risks to living organisms and disrupting ecosystem balance. This study successfully identified gut bacteria from local Indonesian mealworms (*Tenebrio molitor*), including *Pseudomonas aeruginosa*, which exhibited degradation rates of 14.4 % for PS and 44.4 % for PE, as well as *Aeromonas salmonicida*, which demonstrated a 16.3 % degradation rate for PET. This achievement not only highlights the microbial diversity present in the mealworm gut but also underscores their potential role as effective biodegradation agents.

In particular, the isolation of *Aeromonas salmonicida* from local mealworm represents the first report emphasizing its specific potential in PET degradation. These findings support the potential application of mealworm gut bacteria as promising natural bioremediation agents to help address global plastic pollution issues. However, this study has several limitations, including its laboratory scale and the focus on single isolates without further exploration of specific enzymatic mechanisms. Therefore, future research involving genomic analysis, in-depth enzymatic characterization, and the development of more effective bacterial consortia is strongly recommended to enhance the potential of mealworm gut bacteria as an innovative and sustainable solution for plastic waste mitigation.

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