Rocznik Ochrona Środowiska
Volume 28 Year 2026 ISSN 2720-7501 pp. 227-234
https://doi.org/10.54740/ros.2026.017 open access
Received: February 2026 Accepted: April 2026 Published: April 2026

GC-MS Characterization of Low-density Polyethylene Degradation Products by Indigenous Bacteria from Landfill Soil in Iraq

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Abstract: Low-density polyethylene (LDPE) is considered a widespread environmental pollutant that threatens ecosystems due to its non-biodegradable nature. However, different types of bacteria could help with the biodegradation process of synthetic LDPE. This study aimed to investigate the capacity of local bacteria to degrade LDPE in landfill soil and to evaluate their degradation efficiency. Fifty bacterial isolates were obtained through enrichment in a mineral salt medium supplemented with LDPE as the sole carbon source. Initial screening was performed using the clear-zone method with polyethylene glycol (PEG), and 7 isolates showed initial degrading activity. Following characterization, *Staphylococcus haemolyticus* and *Acinetobacter baumannii* were found to possess the highest potential degrading capacity. After 60 days of incubation, the degrading capacity was assessed by measuring the weight loss of LDPE sheets. *S. haemolyticus* recorded a 20% potential weight loss, while *A. baumannii* complex achieved the highest weight loss at 27.5%. The control sample showed no significant weight change. To confirm chemical changes in the polymer, GC-MS analysis of the degradation products was performed. The bacterial-treated samples showed a range of organic compounds, including fatty acid derivatives, aromatic acids, and esters, while no peaks were recorded in the control sample. These results indicate oxidation and gradual breakdown of the polyethylene hydrocarbon chains, leading to the formation of low-molecular-weight compounds that can enter bacterial metabolic pathways. The correlation between weight loss and the appearance of chemical degradation products also reflects partial biodegradation of the plastic. This study highlights the environmental importance of landfill sites as natural sources for isolating bacteria that can adapt to and break down plastics, thereby opening prospects for using these microorganisms to develop bioremediation technologies to reduce the accumulation of plastic waste in the environment.

Keywords: Biodegradation, Dumpsite soils, Low-density polyethylene (LDPE), Indigenous bacteria, GC-MS characterization

1. Introduction

In recent decades, the world has witnessed a tremendous increase in petroleum-derived plastic production, with global production rising from around 1.3 million tons in 1950 to more than 400 million tons annually in the last decade, with only 21% being recycled, while the majority is dumped in landfills or the natural environment, leading to the accumulation of huge amounts of plastic in soil, water, and air (Geyer et al., 2017; Yuan et al., 2020; Ramos et al., 2024). One of the most widely used plastics in the world is polyethylene (PE), which has been considered non-degradable for decades and accounts for approximately 96% of all plastics on the market (Khandare et al., 2021). Among the different types of polyethylene, low-density polyethylene (LDPE) is one of the most common plastics used in packaging, bags, and single-use items due to its low cost, flexibility, and chemical stability. Approximately 69% of all plastic waste in landfills consists of LDPE bags (Khampratueng et al., 2024; Selvaraj et al., 2025). LDPE is essentially a carbon-chain polymer with C–C backbones joined by sigma bonds, making it highly resistant to natural degradation in terrestrial and aquatic environments and prolonging its persistence for decades after disposal (Yao et al., 2022). Over time, these materials gradually break down into tiny plastic particles, known as microplastics, which can migrate through soil, water, and food, causing long-term environmental and health effects (Mendoza et al., 2025). These particles were detected in the intestines of fish at rates of up to 73% in some coastal areas, and they have also been observed in drinking water and the air, posing a growing health risk (Smith et al., 2018; Rochman et al., 2019). The risks of plastic pollution are not limited to environmental impacts but extend to human health, where continuous exposure to microplastics may be linked to inflammatory disorders, hormonal dysfunction, and cumulative toxic effects on vital organs, making the treatment of this waste an environmental and health challenge (Wright et al., 2017; Campanale et al., 2020). Conventional methods of plastic waste management have not adequately addressed the extent of plastic pollution. However, these methods, including landfilling, incineration, and recycling, are failing to offer a long-term, sustainable solution and are

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contributing to environmental degradation (Wafaa et al., 2025). Biodegradation of plastics by microorganisms has gained attention as an eco-friendly and effective method of disposal (Taghavi et al., 2021; Asiandu et al., 2021; Maroof et al., 2021). Microorganisms use plastic polymers as a source of carbon and energy, breaking them down via a variety of metabolic reactions to support vital cellular processes. In addition to serving as a carbon source, plastic provides microorganisms with an ecological niche by supporting their growth and colonization. Biodegradation can occur under aerobic and anaerobic conditions, with aerobic bacteria using oxygen to break down polymers into carbon dioxide, water, and biomass (Tirkey & Upadhyay, 2025). Enzymes break down plastic polymers during biodegradation. This intricate process begins with biodeterioration, a stage in which the polymer's structure chemically changes. The main cause is oxidation, which increases the number of carbonyl (C—O) and carbon–carbon double bonds (C—C). The enzymatic hydrolysis of the altered chemical bonds, known as Bio-fragmentation, is enabled by this chemical alteration of the polymer chains. During this phase, oligomers such as aldehydes, carboxylic acids, and linear alkanes are released. These more polar oligomers can then be bio-assimilated or metabolized and consumed by bacteria to support their growth (Rong & Wu, 2024).

To achieve a holistic understanding of LDPE biodegradation, it is imperative to correlate structural surface alterations with internal chemical transitions (Restrepo-Flórez et al., 2014). While microbial colonization typically initiates through surface attachment—leading to observable topographic changes such as pitting and cracking—these physical markers must be substantiated by molecular evidence (Arutchelvi et al., 2008). Consequently, this study integrates GC–MS analysis to identify specific metabolic intermediates arising from the enzymatic cleavage of the polymer's covalent backbone (Kumar et al., 2024). The synergy between topographic profiling and chromatographic identification ensures robust differentiation between genuine biotic degradation and abiotic processes, such as environmental weathering or additive leaching (Gewert et al., 2015).

Numerous studies have shown that different bacterial species have distinct capacities to degrade LDPE. A study by Das and Kumar reported 16% weight loss in LDPE film after 60 days of incubation with two strains of *Bacillus amyloliquefaciens* (Devi et al., 2019). A study by Devi et al. reported that three marine bacterial isolates, Kocuria palustris M16, Bacillus pumilus M27, and Bacillus subtilis H1584, were able to degrade LDPE film after 30 days of incubation, with weight losses of 1%, 1.5%, and 1.75%, respectively (Khandare et al., 2022). A study by Khandare et al. observed a weight loss of up to 1.68 within 90 days of degradation by the marine bacterium Marinobacter sp. H-246 (Jayan et al., 2023). A study by Jayan et al. reported a 43% weight loss over 120 days with *Bacillus cereus* NJD 1 isolated from landfills (Jayan et al., 2023). Although numerous researchers have demonstrated bacterial and fungal degradation of LDPE, substantial degradation of LDPE waste for environmental applications has yet to be achieved (Montazer et al., 2021). The goal of this study was to identify native bacterial isolates capable of degrading LDPE plastic from soil samples containing municipal plastic waste and to identify the biodegradation intermediates.

2. Materials and Methods

2.1. LDPE Powder and Sheet

LDPE powder with a molar mass range from 20,000 to 150,000 g/mol and a particle size of 400 µm or smaller (screen retention of 50 mesh is 4.4%) was used in primary isolation (Montazer et al., 2021). The powder was rinsed with 95% ethanol, dried in a hot-air oven at 50°C overnight, and then stored at room temperature for later use. The required LDPE sheets for the biodegradation experiment were obtained from a local market. The sheet was washed with distilled water and cut into uniform (2 cm × 2 cm) pieces with a thickness of 40–80 µm. The pieces were sterilized using 70% ethanol for 30 minutes, then dried overnight in a hot-air oven at 50°C, followed by UV treatment for 15 minutes to sterilize (Nademo et al., 2023).

2.2. Sample Collection

From solid waste landfills located in Al-Shnafiya and Afak, Diwaniyah, Al-Qadisiyah Province, Iraq, soil samples were collected. Using closed, sterile containers, 10 samples were randomly selected from various locations and brought to the lab in an ice box. Before use, the samples were homogenized and stored at 4°C (Maroof et al., 2021; Nademo et al., 2023).

2.3. Sample Processing and Bacterial Isolation

Bacteria capable of utilizing LDPE as their sole carbon source were isolated through culture enrichment. The process began by suspending 1 g of the soil sample in 50 mL of sterile saline water, followed by incubation on a rotary shaker at 120 rpm for 4 hours. Subsequently, 5 mL of the soil suspension was inoculated into

a 250 mL Erlenmeyer flask containing 100 mL of sterile mineral salts broth (1 g/L K_2HPO_4, 0.2 g/L KH_2PO_4, 1 g/L $(NH_4)_2SO_4$, 0.5 g/L $MgSO_4{\cdot}7H_2O$, 1 g/L NaCl, 0.01 g/L $FeSO_4{\cdot}7H_2O$, 0.002 g/L $CaCl_2{\cdot}2H_2O$, 0.001 g/L $MnSO_4{\cdot}7H_2O$, 0.001 g/L $CuSO_4{\cdot}5H_2O$, 0.001 g/L $ZnSO_4{\cdot}7H_2O$ and pH 7.0) and 0.2% (w/v) sterilize LDPE powder. All Erlenmeyer flasks were incubated in a shaker incubator at 35°C and 120 rpm. After one week of growth, 5 mL of the enriched culture was transferred to 100 mL of fresh mineral salts broth medium supplemented with 0.2% (w/v) LDPE powder. The third and fourth transfers followed under identical conditions. After four enrichment cycles, 0.1 mL of the diluted sample was spread onto nutrient agar plates and incubated at 35°C for 72 hours (Nademo et al., 2023).

2.4. Screening of LDPE Degrading Bacterial Isolates by the Clear Zone Method

Bacterial isolates were screened for LDPE-degradation potential using the clear zone method. The synthetic medium for detecting clear zones around colonies was prepared by incorporating polyethylene glycol (a soluble polyethylene analog) into mineral salts medium at 0.2% (w/v), solidified with 15% (w/v) agar. The medium was autoclaved at 121°C under 15 psi for 15 min, cooled to 45°C, and poured into sterile Petri dishes. After solidification, isolated colonies from the nutrient agar were cultured using a sterile loop and incubated at 35°C for two weeks. Following incubation, plates were stained with 0.1% (w/v) Coomassie Brilliant Blue R-250 solution—prepared by dissolving the dye in 40% (v/v) methanol and 10% (v/v) acetic acid—for 20 min. Excess stain was decanted, and plates were destained by flooding with a solution of 40% (v/v) methanol in 10% (v/v) acetic acid for 20 min. Isolates exhibiting clear zones against a blue background were identified as polyethylene degraders (Nademo et al., 2023).

2.5. Biodegradation Studies

To conical flasks containing 50 mL of sterile mineral salt medium, sterilized LDPE pieces (2 cm x 2 cm) were preweighted and aseptically introduced as the sole source of carbon, and then 2.5 mL of washed suspension (approximately 10^8 cells per mL) was added. An uninoculated flask containing sterilized LDPE sheets in medium served as the negative control. The flasks were incubated for 60 days at 35°C and 120 rpm on a rotary shaker. The weight-loss method was used to assess the degree of biodegradation of the LDPE sheet following a 60-day incubation period (Maroof et al., 2021; Nademo et al., 2023).

2.6. Determination of the Dry Weight of the Residual LDPE

The LDPE sheets were gathered and combined with 2% (w/v) aqueous sodium dodecyl sulfate (SDS). To remove bacterial film and residual medium, the mixture was washed with distilled water after incubation for 4 hours at 120 rpm in a shaker incubator. The remaining LDPE sheets were collected on filter paper and dried for 24 hours at 60°C. The following formula was used to compute and compare the weight loss (Montazer et al., 2019):

$$\text{Weight loss percentage (\%)} = \text{Initial weight - Final weight/Initial weight} \times 100$$

2.7. Identification of LDPE Degrading Bacterial Isolates

Following standard procedures outlined in Bergey's Manual of Determinative Bacteriology, colony morphological criteria on agar plates and microscopic characteristics using Gram staining were used for the initial identification of LDPE-degrading bacterial isolates (Pincus, 2006). Further identification was performed using the VITEK®2 automated compact system (Pincus, 2006). However, for definitive diagnosis, 16S rRNA gene sequencing is considered the gold standard for identification. Therefore, the VITEK 2 System is considered less specific as its database may lack some environmental bacteria.

2.8. GCMS Analysis of the Degraded LDPE

GC-MS was used to evaluate the LDPE degradation products from bacterial breakdown. After 60 days of incubation, 10 mL of the inoculated culture and 10 mL of the negative control were centrifuged at 10,000 × g and 4°C for 30 min to collect the supernatant. Degradation products were extracted twice: (1) Introduced an equivalent volume of ethyl acetate, sonicated for 20 minutes, let to rest for 2 hours, and collected the upper extraction layer; (2) Introduced an equivalent volume of dichloromethane to the liquid sample, sonicated for 20 minutes, allowed to rest for 2 hours, and collected the lower extraction layer. All extracts were dehydrated utilizing a nitrogen blow apparatus and subsequently dissolved in a 1 mL mixture of dichloromethane and methanol (1:1), employing glass containers and pipettes during the procedure. A TG-5 ms column was used for analysis on a Focus DSQ II GC-MS system, with the injection port temperature set to 270°C. The column temperature was maintained at 50°C for 4 minutes, then elevated to 270°C at 20°C/min, and ultimately held at 270°C for 15 minutes before injection. The flow rate was established at 1 mL/min with helium as the car-

rier gas, while scanning for ion/fragment signals within the range of 40–600 Amu (Zhang et al., 2023). The final mass spectra were compared with chemicals in the NIST collection to identify possible degradation products (Restrepo-Flórez et al., 2014).

3. Results

3.1. Isolation of LDPE Degrading Bacteria

Following a series of culture enrichments using mineral salt broth supplemented with 0.2% LDPE powder, a total of 50 bacterial isolates that thrived on LDPE as their sole carbon source were isolated on nutrient agar (Figure 1).

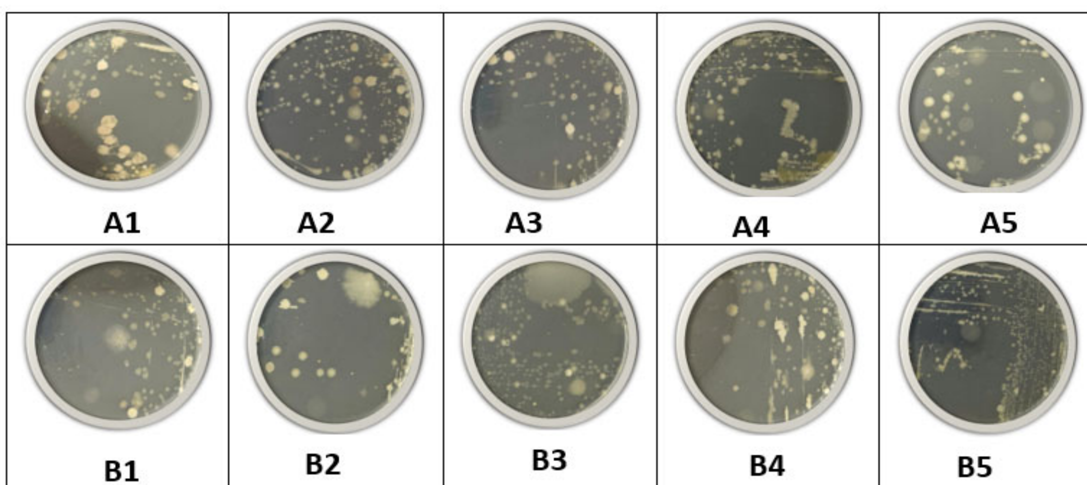

Fig. 1. Growth of bacterial colonies on nutrient agar following enrichment in MSM supplemented with LDPE

3.2. Screening of LDPE Degrading Bacterial Isolates by the Clear Zone Method

The clear zone method was used for the initial screening of the bacterial isolates for LDPE degradation, where only seven of the fifty bacterial isolates showed a discernible clear zone surrounding their growth and were selected for further study (Figure 2).

Fig. 2. Initial screening of bacterial isolates on MSM agar supplemented with PEG, showing (A) a positive isolate with transparent areas around growth; (B) no transparent areas around growth

3.3. LDPE Degradation Assay and Change in the Weight of LDPE

The degradation of LDPE sheets was assessed after 60 days of incubation by weighing them before and after the experiment. The results in Table 1 showed the degree of degradation for each strain tested along with the control. The control sample maintained a stable weight, with no loss, and the initial and final weights remained at 0.040 g, indicating no degradation in the absence of bacterial activity. Of the seven bacterial isolates that showed a clear zone around their colonies, only two caused weight loss in LDPE sheets. B5 (1) isolate showed a 20% weight loss, decreasing from 0.040 to 0.032 g. B5 (2) isolate exhibited the highest degradation rate, with a weight loss of 27.5%, decreasing from 0.040 to 0.029 g. These results indi-

cated a change in the LDPE structure following bacterial treatment. The two LDPE-degrading bacterial isolates were identified using VITEK 2, where B1 (2) was identified as S. haemolyticus with a reliability rate of 94% and B5 as *A. baumannii* complex with a confidence level of 99%.

Table 1. Comparative Effect of Selected Bacterial Species on Weight Loss Percentage After 60 Days

Bacterial code	Bacterial species	Initial weight (g)	Weight after 60 days (g)	Weight loss percentage (%)
Control	No bacteria	0.040 ± 0.00	0.040±0.00	0 %
B5 (1)	*S. haemolyticus*	0.040±0.00	0.032±0.01	20% *
B5 (2)	*A. baumannii* complex	0.040±0.00	0.029±0.01	27.5%*

(P < 0.05) =*

3.4. GC-MS Analysis of Degradation Products

GC-MS analysis of LDPE sheets after 60 days of incubation revealed a clear difference between the control and bacterially treated samples. The control sample showed no detectable peaks in the chromatogram. In contrast, the samples treated with the two bacterial isolates showed the appearance of several chemical peaks at different retention times, and a range of new organic compounds were identified, including fatty acid derivatives such as hexadecanoic acid, aromatic acid derivatives such as benzoic acid and mandelic acid, as well as some organic acids and esters. The *Acinetobacter baumannii* complex was characterized by the appearance of a greater number of compounds compared to *Staphylococcus haemolyticus*, reflecting chemical changes in the LDPE structure after bacterial treatment. These results, when compared with the peak-free control sample, suggest that the appearance of these compounds is related to the biological treatment of the material rather than to the extraction materials or analytical conditions.

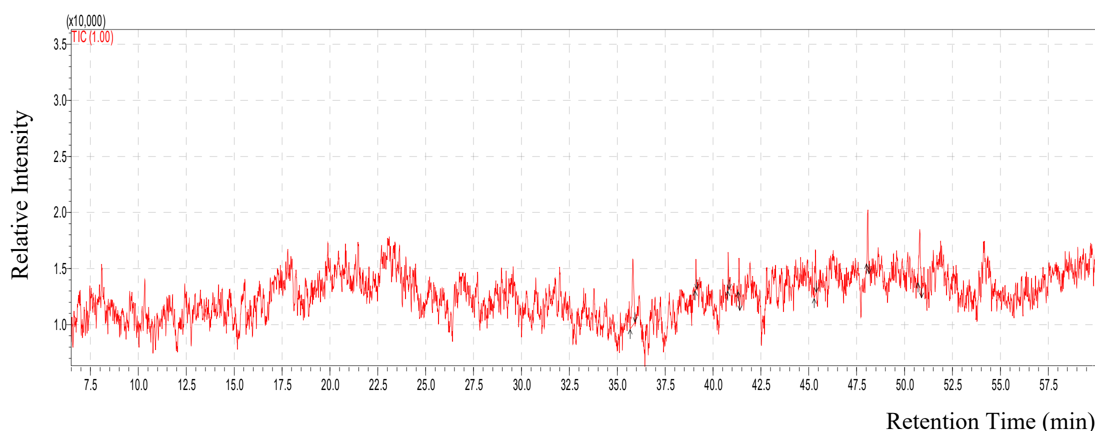

Fig. 3. GC-MS chromatogram of LDPE treated with *S. haemolyticus*

Table 2. Compounds identified in LDPE treated with *S. haemolyticus*

NO.	Ret.Time	Name
1	35.658	Mandelic acid di(tert-butyldimethylsilyl)-
2	39.150	Hexadecanoic acid, 1a,2,5,5a,6,9,10,10a-octahydro-5a-hydroxy-4-(hydroxymethyl)-1,1,7,9-tetramethyl-6,11-dioxo-1H-2,8a-methanocy
3	40.842	5-Methoxy-6-trimethylsilyloxy-2-indolecarboxylic acid, trimethylsilyl ester
4	41.317	Benzoic acid, 4-bromo-3-nitro-
5	45.275	Acetic acid, bis[(trimethylsilyl)oxyl]-, trimethylsilyl ester
6	48.150	Heptasiloxane, 1,1,3,3,5,5,7,7,9,9,11,11,13,13-tetradecamethyl-
7	50.700	Mercaptoacetic acid, bis(trimethylsilyl)-

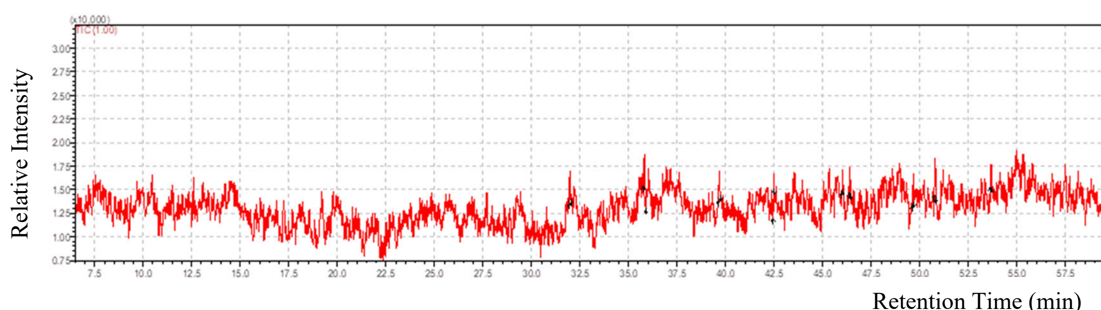

Fig. 4. GC-MS chromatogram of LDPE treated with *Acinetobacter baumannii* complex

Table 3. Compounds identified in LDPE treated with *Acinetobacter baumannii*

NO.	Ret.Time	Name
1	35.900	Mandelic acid di(tert-butyldimethylsilyl)-
2	39.617	2-Nitrophenyl (diethylamino)methanethioate
3	42.408	Benzoic acid, 2,6-bis[(trimethylsilyl)oxy]-, trimethylsilyl ester
4	46.033	Acetic acid, 17-(1-hydroxy-ethyl)-10,13-dimethyl-2,3,4,7,8,9,10,11,12,13,16,17-dodecahydro-1H-cyclopenta[a]phenanthren-3-yl est
5	46.350	2-Pentenedioic acid, 2-methyl-, bis(tert-butyldimethylsilyl) ester
6	49.608	Hexadecanoic acid, (2,2-dimethyl-1,3-dioxolan-4-yl)methyl ester
7	50.717	Heptasiloxane, 1,1,3,3,5,5,7,7,9,9,11,11,13,13-tetradecamethyl-
8	53.717	1,2-Benzenedicarboxylic acid, ditridecyl ester

4. Discussion

Landfill sites are selective environments rich in organic and plastic pollutants, making them natural reservoirs for microorganisms that can adapt to and colonize polymeric compounds. Prolonged exposure to plastics leads to the development of microbial communities capable of adhering to hydrophobic surfaces and forming biofilms that initiate the degradation process. Soil samples taken from landfill areas are a rich source for isolating bacterial strains capable of growing in media containing LDPE. This demonstrates their adaptation to hydrophobic surfaces and their ability to secrete extracellular enzymes that help break down polymers and convert them into simpler, bioavailable compounds (Arutchelvi et al., 2009; Khampratueng et al., 2024). The enrichment method using a mineral salt medium containing LDPE as the sole carbon source has helped in selecting the most adaptable isolates to this material, a method used in polyethylene degradation studies to recover functionally specialized bacteria (Restrepo-Flórez et al., 2014). Furthermore, the use of the transparent halo formation around colonies with PEG as a preliminary indicator of degradation is a qualitative screening tool for selecting candidate isolates. The appearance of degradation zones indicates the bacteria's ability to secrete enzymes that can react with polymeric substrates or their derivatives. However, this test does not provide conclusive evidence of LDPE degradation and requires support from quantitative measurements, such as weight loss and chemical analysis (Arutchelvi et al., 2008). The weight-loss results from this study showed that *S. haemolyticus* and *A. baumannii* induced clear changes in LDPE sheets after the incubation period, with losses of 20% and 27.5%, respectively. In contrast, the control sample showed no change. This suggests physical degradation related to bacterial activity. It has been shown that microbial degradation of polyethylene typically begins with a surface oxidation stage that weakens carbon-carbon bonds and facilitates chain dissociation (Hadad et al., 2005). Studies indicate that *Acinetobacter* can react with low-density polyethylene (LDPE).

Some species, such as *A. baumannii*, have demonstrated the ability to grow in media containing LDPE as the sole carbon source, with clear changes in the polymer's chemical structure detected by FTIR spectroscopy. This activity was associated with the emergence of new carbonyl groups and alterations in chemical bonds, indicating progressive oxidation of the hydrocarbon chains (Pramila & Ramesh, 2015). Other species, such as *A. guillouiae*, have been isolated and shown to degrade polyethylene through weight loss, surface erosion, and the formation of metabolic byproducts, suggesting their role in utilizing the alkanes produced from polymer degradation as an energy source (Kim et al., 2023). *Staphylococci* are widespread and adaptable to diverse environments. They possess remarkable enzymatic capabilities, including the production of lipases and proteases, enzymes that can initiate oxidation and surface degradation of polymers. Studies have

shown that certain Staphylococcus species can reduce LDPE weight over time under suitable conditions, due to cell adhesion to the polymer surface and the formation of biofilms that facilitate degradation (Tamnou et al., 2022). GC-MS results supported this interpretation, showing the presence of a range of organic compounds in the treated samples, including fatty acid derivatives, aromatic acids, and esters. In contrast, no peaks were observed in the control sample. This confirms that these compounds resulted from chemical changes in the polymer structure and not from solvents or preparation steps. The appearance of fatty acid derivatives, such as hexadecanoic acid, indicates the initial oxidation of long hydrocarbon chains, followed by progressive cleavage, resulting in smaller, more polar molecules that can subsequently enter metabolic pathways. Fatty acids are converted via the β-oxidation pathway to acetyl-CoA, which enters the TCA cycle to produce energy (Gewert et al., 2015). However, it is difficult to differentiate between fatty acids derived from biodegradation and those originating from natural bacterial metabolism as direct metabolites. The appearance of benzoic acid and mandelic acid derivatives may reflect advanced oxidation reactions or the transformation of intermediate products resulting from chain breakdown. Studies indicate that microbial degradation of polyethylene involves successive stages, beginning with oxidation, followed by fragmentation into smaller molecules, such as organic acids, alcohols, and aldehydes, which can subsequently be metabolized by bacterial cells (Restrepo-Flórez et al., 2014). Recent studies have also supported these findings by monitoring similar products using GC-MS during the degradation of polyethylene by bacteria isolated from contaminated environments (Zampolli et al., 2024). The consistency between weight loss and the appearance of new chemical products with their absence in control provides complete evidence of partial biodegradation of polyethylene, and indicates that bacteria isolated from landfill sites possess adaptive mechanisms that enable them to colonize plastic surfaces and begin to gradually break them down through a series of oxidative and metabolic processes, which supports the role of these environments as an important source for isolating microorganisms that can be invested in the future in the bioremediation of plastic waste (Shah et al., 2008; Gewert et al., 2015).

Even though physical factors may affect mass loss, GC-MS is crucial for demonstrating chemical change. This technique not only quantifies the loss but also accurately identifies the intermediary compounds formed by bond cleavage in the plant environment. "As established by (Albertsson & Hakkarainen, 2017), the identification of specific oxidation metabolites and short-chain oligomers via GC–MS serves as definitive evidence of enzymatic cleavage within the polymer's covalent framework. Such molecular-level insights provide qualitative validation of chemical transformations that conventional physical assessments, such as mass loss, cannot substantiate independently, as they cannot distinguish between true biochemical degradation and mere mechanical fragmentation. "Furthermore, (Ghosh et al., 2013) underscore that the capacity of GC–MS to isolate and characterize volatile and semi-volatile organic compounds facilitates the mapping of complex metabolic pathways. This analytical depth substantiates the hypothesis that the observed alterations are not merely a result of additive leaching but rather the product of intricate biochemical reactions. Such processes lead to the synthesis of novel derivative compounds that were inherently absent in the original polymer matrix."

5. Conclusion

The results of this study show that bacteria isolated from landfill sites clearly can induce partial degradation of LDPE sheets, as reflected in weight loss and the formation of organic compounds resulting from the breakdown of hydrocarbon chains. *S. haemolyticus* and *A. baumannii* complex exhibited the highest efficacy in affecting the physicochemical structure of the polymer. The correlation between the weight-loss results and the GC-MS analysis confirms actual changes in the plastic's composition. These findings suggest the potential application of local bacterial isolates in the bioremediation of plastic waste.

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