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Original Article

Biodegradation Potential of LDPE-Degrading Bacteria Isolated from Long-Term Plastic Landfills in Madurai

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Abstract

Low-density polyethylene (LDPE) is widely used but poses serious environmental and health risks when improperly discarded, highlighting the need for effective waste management. Conventional disposal methods are inadequate, making microbial bioremediation a promising and sustainable alternative for plastic degradation. This study aimed to investigate the potential of novel bacterial isolates obtained from long-term plastic waste landfills to degrade LDPE by utilizing polyethylene as their sole carbon source. Partial sequencing of the 16S rRNA gene identified *Acinetobacter bereziniae* (PD6), *Staphylococcus epidermidis* (PD9), and *Bacillus cereus* (PD13) as potential LDPE-degrading bacteria among 14 isolates. The biodegradation of LDPE films was evaluated through weight loss analysis, which revealed no significant variation among the isolates: *Acinetobacter bereziniae* (0.426%), *Staphylococcus epidermidis* (0.280%), and *Bacillus cereus* (0.390%) after 90 days of incubation. Fourier-transform infrared (FTIR) analysis exhibited $-CH_2$ asymmetric and symmetric stretching bands, accompanied by the emergence of new peaks, while scanning electron microscopy (SEM) confirmed morphological changes in LDPE induced by bacterial biofilm formation. Degradation products identified using GC-MS included n-hexadecanoic acid, 2H-2,4a-methanonaphthalen-8(5H)-one, diethyl phthalate, nonanal, 6-octadecenoic acid (Z), palmitic acid, 9-hexadecenyl ester (Z), oleic acid, bis(2-ethylhexyl) phthalate, decanedioic acid, and bis(2-ethylhexyl) ester. This study highlights the isolation of LDPE-degrading bacterial strains from long-term plastic-contaminated landfill soils, suggesting their adaptive evolution and enhanced capability to utilize polyethylene as their sole carbon source.

Keywords: *Biodegradation; Long-Term Plastic Landfills; Low Density Polyethylene; Plastic Pollution; Recalcitrant; Waste Disposal*

Introduction

A fine innovation of multi-utility polymer material finds its enormous production (Zbyszewski & Corcoran, 2011) and becomes an inseparable component of our current lives (Evode *et al.,* 2021). High-Density Polyethylene (HDPE) and Low-Density Polyethylene (LDPE) are ethylene-derived long-chain polymers extensively utilized in the packaging industry due to their light weight, cost-effectiveness, durability, energy efficiency and ease of processing (Rivard 1995; Witt 2001; Müller 2001). Due to its increasing demand, global plastic production has reached 368 million tons per annum and it is further estimated to double by 2040 (Geyer *et al.,* 2017; Plastic Europe, 2018). The production and utilization of plastics in India are comparatively higher, as 24 million tonnes of plastic consumption were estimated per annum and about 25 percent are used to be discarded as plastic waste (Aryan *et*

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al., 2019). Eventually about 80% of plastics are made to accumulate in the natural environment (Liang *et al.,* 2021). The disposal without adopting the proper management practices generally in every part of the globe becomes a huge menace and this plastic pollution has become a severe transboundary threat to natural ecosystems, human health and sustainability (Silva *et al.,* 2021).

The disposal of plastic materials through chemical and physical methods is very expensive and generates persistent organic pollutants (POPs), such as furans and dioxins (Kyaw *et al*., 2012). These contaminants are reported to be highly toxic, as they form irritant by-products that lead to soil infertility, hinder the degradation of other natural substances, deplete underground water resources, and pose significant threats to animals, humans, and ecosystems (Kyaw *et al*., 2012).As a result of poor waste management, ineffective safe disposal techniques, and contamination from food or chemicals, only around 9% of the plastic trash generated has ever been recycled; the rest has either been dumped in landfills or dumps, burned, or left lying around (UNEP). Consequently, plastic pollution is spreading rapidly across various environments, including soil, sediments, agricultural land, the sea, surface waters, water streams, and sludges. The effects of plastic pollution on animals can be either subtle (e.g., altered behavior or reduced fitness) (Mattsson *et al*., 2017) or obvious, such as entanglement and starvation (Laist, 1997), as ingested plastics may relate to dietary dilution and lack of essential nutrients (Roman *et al*., 2020). Long-term human exposure to plastics (such as microplastics) can alter human chromosomes and increase the risk of obesity, infertility, and even cancer (GESAMP, 2015).

Alternatively, various methods are also employed for managing plastic waste. Recent technologies used in plastic waste management for energy recovery include polymer blended bitumen roads (Munera & Ossa, 2014), plasma pyrolysis (Punčochář *et al*., 2012), co-processing of plastic waste in cement kilns (Prakash & Palkar, 2023), and the production of liquid fuel (Mahari *et al*., 2018). But the net energy production is very low. The biological degradation of plastics is therefore considered an economical and efficient tool for remediating hazardous waste-contaminated surroundings. During biodegradation, plastics undergo oxidation upon reacting with atmospheric oxygen, after which microorganisms secrete polyethylene-degrading enzymes that further break down the polymers to obtain energy, resulting in smaller by-products such as carbon dioxide and water (Albertsson *et al*., 1998).

Microorganisms utilize waste materials as substrates and produce extracellular enzymes that degrade polymers into simpler molecules, dimers and monomers (Howard *et al*., 1999). Low-molecular-weight compounds generated during degradation can penetrate semi-permeable membranes and serve as substrates for microbial carbon and energy metabolism (Gu, 2003). They play a vital role in mitigating environmental pollution by degrading waste materials, including plastics, in landfills and soil, ultimately yielding beneficial organic fertilizers. Being eco-friendly, they break down a wide range of cellulose, lignin, and plastic-rich debris, thereby recycling organic matter and ultimately releasing carbon dioxide and water (Negi *et al*., 2009).

There has been a steady increase in research on the microbial decomposition of plastic waste, particularly polyethylene, which is extremely resistant (Harshvardhan & Jha, 2013; Muenmee *et al*., 2015; Muenmee *et al*., 2016; Veethahavya *et al*., 2016). Many microbial species have been reported to degrade LDPE in the last two decades, including gram-positive and gram-negative bacteria belonging to the genera *Brevibacillus (Hadad et al*., 2005) and *Staphylococcus* (Nowak *et al*., 2011). *Bacillus* (Harshvardhan & Jha, 2013), *Pseudomonas* (Tribedi & Sil, 2013), *Klebsiella and Enterobacter (*Wróbel *et al., 2023)*, *Chryseobacterium and Methylorubrum* (Cabeza-Vásquez *et al*., 2025), *Nitratireductor and Gordonia (Rong et al*., 2024) were isolated from plastic-contaminated soil. Although several microorganisms are known to degrade polyethylene, its high molecular weight, complex three-dimensional structure, and hydrophobic properties hinder efficient degradation (Ribitsch *et al*., 2012; Yoshida *et al*., 2016). Moreover, there is still limited knowledge regarding how these organic polymers persist in the environment and how long they take to undergo complete mineralization into CO_2 (Wojnowska-Baryła *et al*., 2022). Hence, the isolation and characterization of novel polyethylene-degrading microorganisms offer promising opportunities to tackle the global challenge of plastic

pollution more effectively and sustainably. It's a crucial step towards developing practical solutions that can complement recycling efforts and reduce the environmental burden of plastic waste.

An attempt is made to investigate the degradation efficiency of bacteria isolated from long-term plastic waste landfills. Evidence of biodegradation was obtained through weight loss measurements, FT-IR, SEM and GC-MS analyses, which were used to evaluate the ability of the bacterial isolates to degrade the LDPE samples.

Materials and Methods

Sample Collection

Six plastic dumping sites, where plastic waste has been deposited for several years, were selected, namely Aanaiyur, Virahanoor, Velakkal, Panaiyur, Uthangudi and Othakadai. The samples were collected from three random sampling locations, with soil taken at a depth of 3-5 cm below the surface. The soil samples collected from three sampling points were pooled together and stored in the airlock bags and preserved under laboratory conditions for further use.

Materials

Low-density polyethylene powder (LDPE) was obtained from Rapid Coat (A Unit of Rapid Engg. Co. Pvt. Ltd.), Pune, India and low-density polyethylene film from Venus's Polymers, Villapuram, Madurai, India.

Isolation of Plastic-Degrading Bacteria through Culture Enrichment

An enrichment technique was employed to isolate microorganisms from the plastic-dumped soil in an effort to provide selective conditions using PE film or powder as the sole source of carbon. Minimal Salt medium (MSM) comprising major elements and micronutrients (pH – 7.0 ± 0.2) was prepared as a growth medium for the isolation of bacterial strains capable of growing on polyethylene film using the standard protocol of Coleman *et al.* (2002) (AEM, JS666), which was originally adopted from Hartmans *et al*. (1992) and Jeon and Kim (2016). Soil samples (10% w/v) were mixed with sterile MSM and 0.1% of PE film was added as a sole carbon source. The enrichment cultures were maintained at room temperature on a rotary shaker (120 rpm) for 7 days. The presence of biofilm on polyethylene sheets was also confirmed by transferring the incubated sheets onto nutrient agar plates to observe bacterial growth. The cultures were then serially diluted, plated on nutrient agar, and incubated at 37 °C for 5 days. Individual colonies were selected based on the colony characteristics and purified by the streaking technique. Pure cultures were maintained in 40% glycerol stock solution and stored at -70°C in a biofreezer.

Screening of LDPE Degrading Bacteria

The clear zone method was used to assess the LDPE-degrading potential of bacterial isolates. The screening agar medium was prepared by supplementing minimal salt medium with LDPE powder (0.5% and 1% w/v) as described by Rosario and Baburaj (2017). Isolates were inoculated onto the medium and incubated at 37 °C for 72 h. To visualize polymer degradation, incubated plates were stained with 0.1% (w/v) Coomassie Brilliant Blue for 20 min and later destained for 10 min. LDPE degradation was indicated by the formation of a transparent zone surrounding the colonies.

Molecular Identification and Phylogenetic Analysis of LDPE Degrading Isolates

The bacterial isolates were identified by 16S rRNA gene sequencing performed by Eurofins Genomics India Pvt. Ltd. The obtained sequences were compared with reference sequences using the NCBI BLAST database. Multiple sequence alignment was carried out using Clustal W, and phylogenetic relationships were constructed using the Neighbor-Joining method (Saitou & Nei, 1987). Branch support was evaluated by bootstrap analysis with 1000 replicates (Felsenstein, 1985). MEGA12 software was used to analyze the evolutionary relationship among the isolates (Kumar *et al.* 2024).

Assessment of LDPE Biodegradation

Untreated LDPE films were used to evaluate the biodegradation ability of the bacterial isolates. Film pieces (2 × 2 cm) were surface-sterilized with 70% ethanol for 30 min and aseptically placed in flasks containing 100 ml sterile minimal medium. Each flask was inoculated with 1 ml of a 24-h bacterial culture and incubated at 35 °C on a rotary shaker for 90 days. An uninoculated medium maintained under the same conditions served as the control. After incubation, degradation was examined by measuring weight loss and by FT-IR, SEM, and GC–MS analyses.

Weight Loss Determination

After 90 days, the films were collected, treated with 2% (w/v) SDS for 4 h to remove attached biomass, rinsed with distilled water, dried, and weighed. Percentage weight reduction was calculated using a standard formula (Montazer *et al*., 2019).

$$Weight\ Loss\ (\%) = \frac{Intial\ Weight - Final\ Weight}{Initial\ Weight} \times 100$$

FT-IR Spectral Analysis of Polyethylene

Structural modifications in the LDPE films were examined using Fourier transform infrared (FT-IR) spectroscopy (Model: IRSpirit). FT-IR scans of all LDPE samples were taken at a spectrum ranging from 400 cm^{-1} to 4000 cm^{-1} at ambient room temperature (Gajendiran *et al.,* 2016). After 90 days of incubation with the bacterial isolates, the LDPE films were collected and washed with 2% SDS, then disinfected with 70% ethanol for 10 mins. The films were then washed with sterile distilled water and dried overnight at 50°C. The structural changes of polyethylene samples incubated with the potential isolates and control were analyzed by Fourier transform infrared (FTIR) spectroscopy. FT-IR spectroscopy detected variations in functional groups, and the corresponding characteristic peaks of the spectra were evaluated with Origin 2024.

Scanning Electron Microscopy (SEM) Analysis of Polyethylene

The PE films surface morphology was characterized by scanning electron microscopy (SEM; VEGA3 TESCAN, Czech Republic). PE films were cut into 2×2cm pieces were incubated with the bacterial isolates for ninety days. After 90days of incubation, the films were collected and washed with 2% SDS then disinfected with 70%ethanol for 10mins. The films were then washed with sterile distilled water and dried overnight at 50°C. The structural and morphological alterations on the surface of polyethylene films, before and after microbial treatment, were examined using Scanning Electron Microscopy (SEM). The corrosion on the film surface caused by micro organisms were examined using SEM images to evaluate the biodegradation ability of the PE degraders.

LDPE Degradation Analysis Using GC-MS

LDPE degradation products were characterized by GC–MS using helium as the carrier gas and diethyl ether as the extraction solvent (Kyaw *et al*., 2012). After incubation, the culture medium containing the LDPE films was centrifuged at 8000 rpm for 5 min at room temperature to remove cellular material. The supernatant was then filtered through Whatman filter paper, and the degradation compounds were recovered by solvent extraction with diethyl ether. Equal volumes of filtrate and solvent were combined and separated using a separating funnel. An aliquot of 1 ml of the ether extract was subsequently injected into the GC–MS system for analysis.

Statistical Analysis

Differences in LDPE film weight reduction among the bacterial isolates were statistically evaluated using one-way ANOVA in SPSS (version 16) (Awasthi *et al*., 2017). Pairwise comparisons were subsequently carried out using the student–Newman–Keuls (SNK) post hoc test, with significance considered at $p < 0.05$ after 90 days of incubation.

Results

Isolation and Identification of LDPE Degrading Bacteria

Samples collected from six plastic landfill sites yielded a total of 14 bacterial isolates (PD1–PD14; Table 1). Preliminary screening for LDPE degradation using the clear zone method identified three isolates (PD6, PD9 and PD13) that produced detectable clear zones around their colonies, indicating LDPE-degrading potential. Molecular identification based on 16S rRNA gene sequencing revealed that the isolates were *Acinetobacter bereziniae* (PD6), *Staphylococcus epidermidis* (PD9), and *Bacillus cereus* (PD13). The DNA sequence data generated in this study have been deposited in the GenBank repository maintained by the National Center for Biotechnology Information (NCBI), with accession numbers PP593934 (PD6), PP593822 (PD9), and PP593831 (PD13). Sequence analysis showed high similarity (99–100%) with previously characterized strains (Figure 1). Taxonomic analysis indicated that two of the identified LDPE-degrading isolates belonged to the phylum Firmicutes (*Bacillus* and *Staphylococcus*), while one isolate belonged to the phylum Proteobacteria (*Acinetobacter*).

Table1: *Location of the Soil Sample and Their Corresponding Isolates*

Soil Sample	Area	Location	No. of Bacterial Isolates	Isolates Code
Sample1	Panaiyur	(9.9111°N, 78.1207°E)	2	PD1 &PD2
Sample2	Uthangudi	(9.9510°N,78.1682°E)	2	PD3 &PD4
Sample3	Aanaiyur	(9.8745°N, 78.1165°E)	3	PD5,PD6&PD7
Sample4	Virahanoor	(9.9019°N, 78.1624°E)	2	PD8 &PD9
Sample5	Othakadai	(9.9584°N, 78.1877°E)	2	PD10 &PD11
Sample6	Velakkal	(9.9609°N, 78.1106°E)	3	PD12, PD13&PD14

**PD stands for Plastic Degrading isolate*

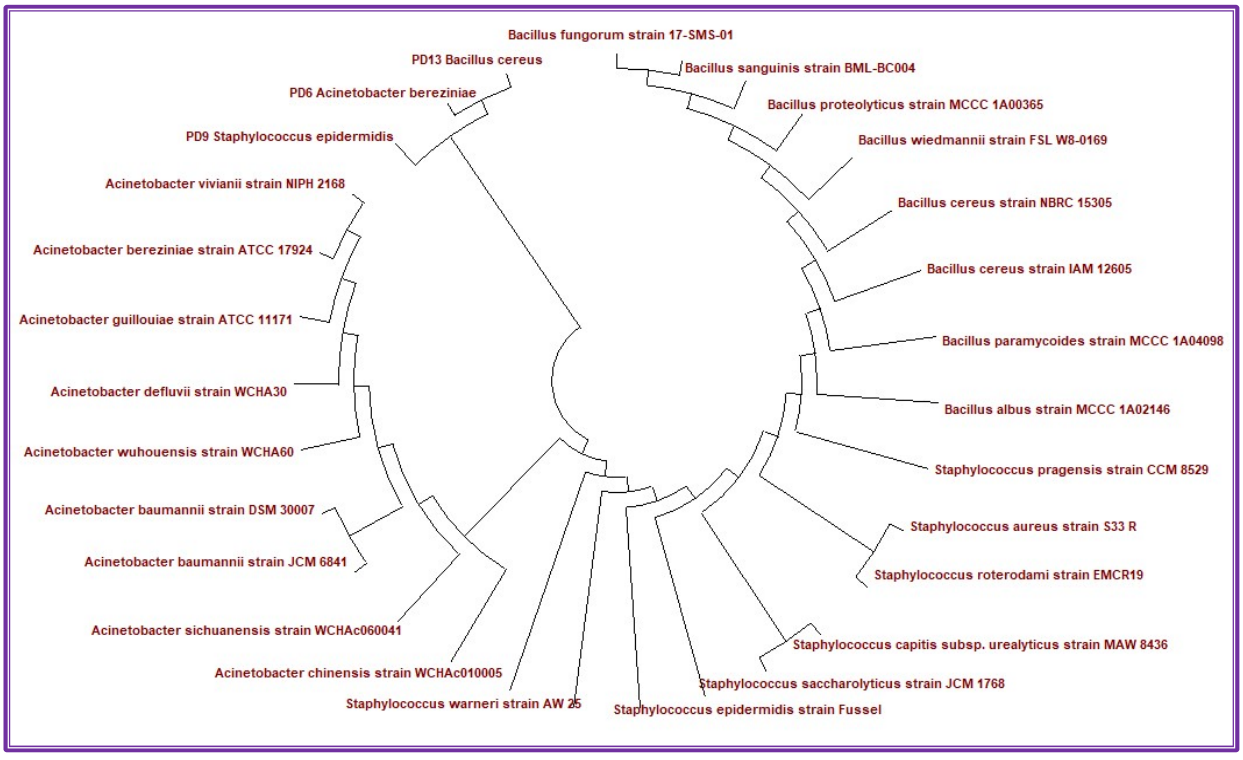


Figure 1: *Phylogenetic Tree Exhibiting the Relationship Among 16S rRNA Gene Sequences of The Isolates Through BLAST Analysis. Clustal W Program Was Used for The Sequence Alignment and The Tree Was Constructed Using Neighborhood-Joining with Kimura 2 Parameter Distances in MEGA 12Software. Bootstrap Values (1000) Replicates Are Shown at The Nodes. Sequences Designated as PD6, PD 9 And PD13 Were Obtained from The Present Study.*

Weight Reduction

The degradation of LDPE films was evaluated by measuring dry weight reduction after incubation with individual bacterial isolates for 90 days. Following incubation, adherent cells were removed and duplicate plastic films were recovered for analysis. The percentage weight loss of LDPE recorded was 0.426 ± 0.2% for *Acinetobacter bereziniae,* 0.280 ± 0.1% for *Staphylococcus epidermidis*, and 0.390 ± 0.2% for Bacillus cereus. No measurable weight loss was observed in the control polyethylene films incubated without bacterial isolates (Table 2).

Table2: *Percentage of Weight Loss of LDPE Film After 90Days of Incubation Differentiated Using SNKTest at P>0.05SignificantLevel. Values Are Triplicates and Expressed as Mean±SE(N=3)*

Isolate	Initial Weight (mg)	Final Weight (mg)	Percentage of Weight Loss ± SE (%)
PD6	24.40	24.16	0.426 ± 0.2^{b}
PD9	22.63	22.56	0.280 ± 0.1^{a}
PD13	24.60	24.53	0.390 ± 0.2^{a}

FT-IR Spectral Analysis of Polyethylene

The FTIR spectra of LDPE films incubated with the bacterial isolates for 90 days showed clear structural modifications. The control spectra of the LDPE film not treated with any of the isolates exhibited distinctive bands characteristic of a typical LDPE at 2950 cm^{-1}, 2917 cm^{-1}, 2867 cm^{-1}, 2837 cm^{-1}, 1745 cm^{-1}, 1456 cm^{-1}, and 1376 cm^{-1} (Fig. 2). Strong peaks at 2950 cm^{-1} and 2917 cm^{-1} correspond to CH_2 asymmetric stretching, 2867 cm^{-1} and 2837 cm^{-1} to CH_2 symmetric stretching, 1456 cm^{-1} to C=C bending deformation and 1376 cm^{-1} to CH_3 symmetric deformation. Although native bands remained intact in the IR spectra of the treated LDPE, new peaks were observed in the spectrum of all the treated LDPE at 2960 cm^{-1} (Fig. 3); however, the intensity of the peaks varied with the treated isolates. The highest peak intensity at 2960 cm^{-1}, representing –CH groups, was observed in LDPE treated with *Acinetobacter bereziniae* (PD6), followed by *Bacillus cereus* (PD9) and *Staphylococcus epidermidis* (PD13). A noticeable reduction in percentage transmittance at 1745 cm^{-1} (ketone region) was also observed after 90 days of incubation with the isolates (Figures 2 & 3).

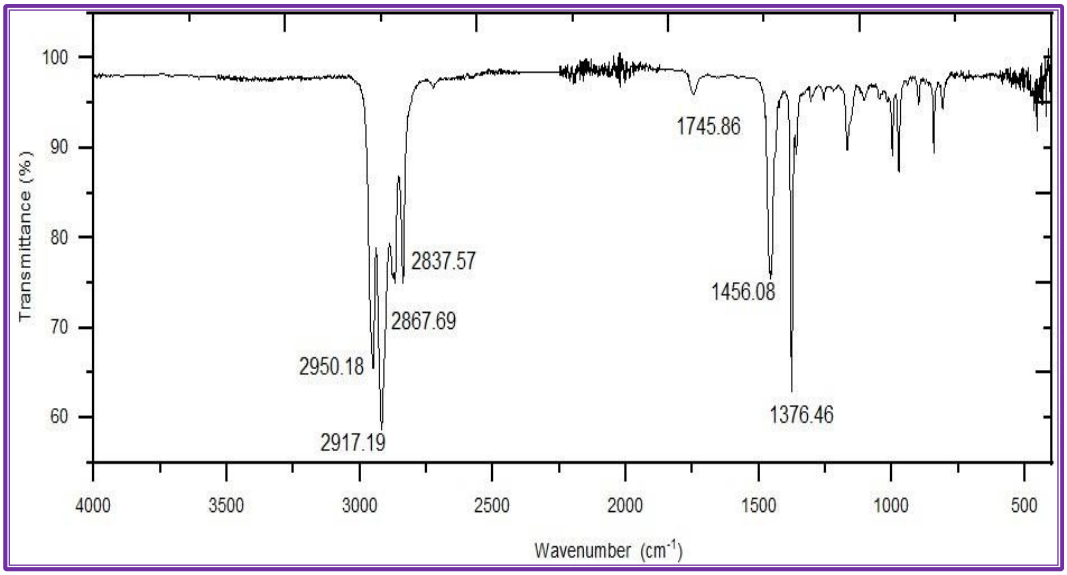


Figure 2*: Fourier Transform Infrared Spectra (FT-IR) of Control LDPE*

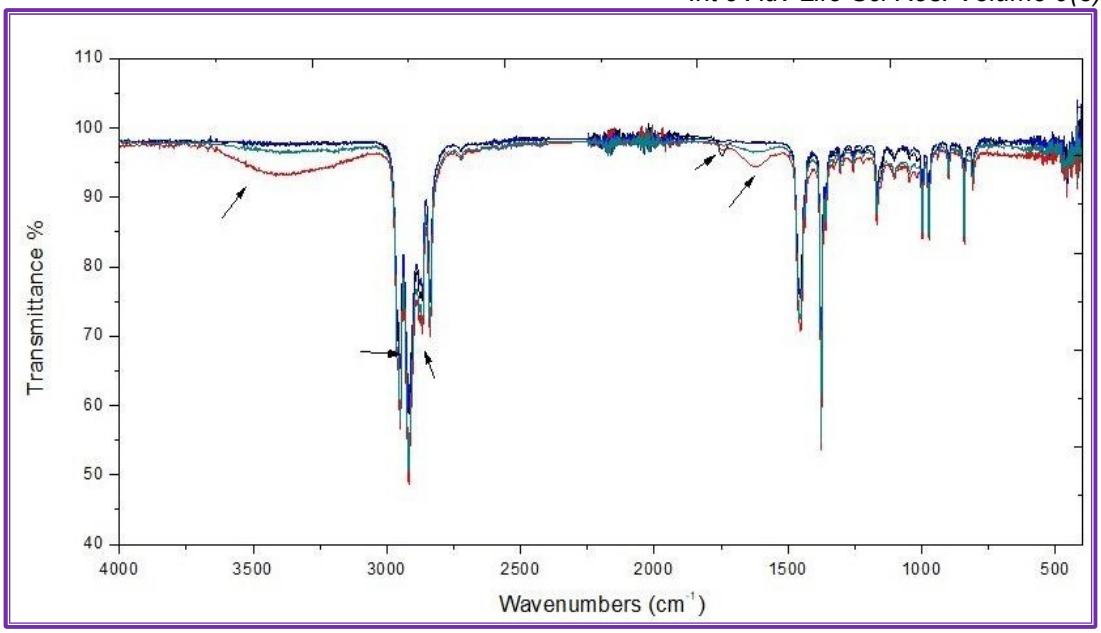
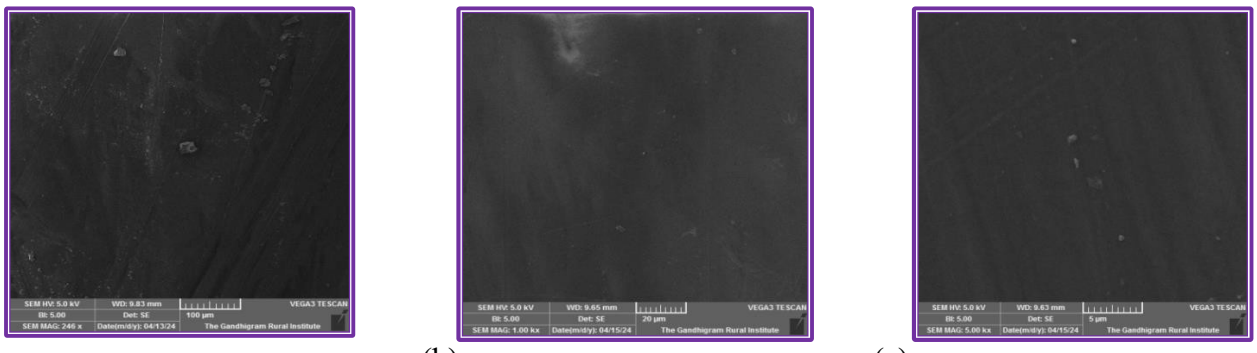


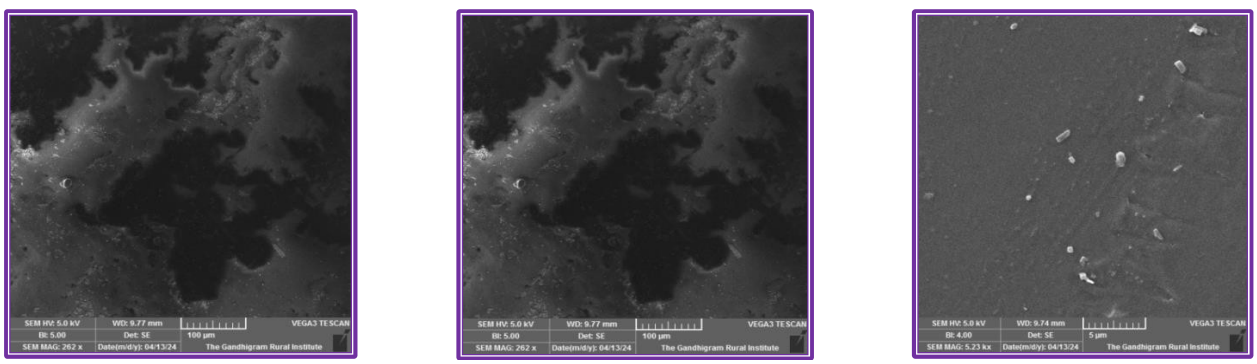
Figure 3: *FT-IR Spectra of LDPE Film After 90 Days of Incubation with Bacterial Isolates. The Colors Indicate the Spectra of LDPE Treated with the Isolate Black–Control(Without Isolate),Red– Acinetobacter bereziniae (PD6), Blue – Staphylococcus epidermidis (PD9),Green –Bacillus cereus (PD13)*

Scanning Electron Microscopy Analysis

SEM micrographs confirmed significant surface degradation of LDPE films after 90 days of incubation. The present investigation revealed that no holes, cracks or particles attached to the surface were observed in the control sample incubated without bacterial isolates (Figure 4 – (a), (b), (c)). In contrast, LDPE films treated with bacterial isolates showed morphological changes characterized by pits, cracks, erosion and roughness (Figures 4(d), (e), (f), (g), (h), (i), (j), (k) & (l)).



(a) (b) (c)



(d) (e) (f)

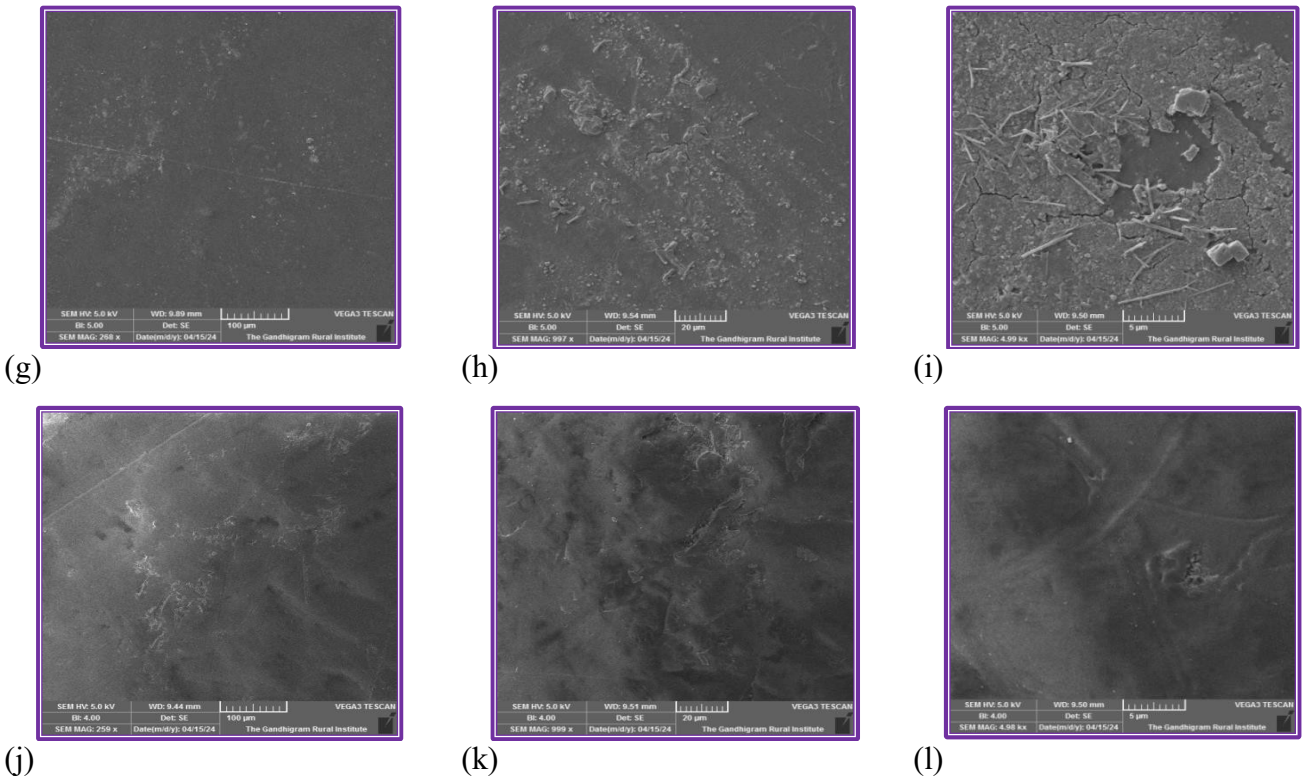
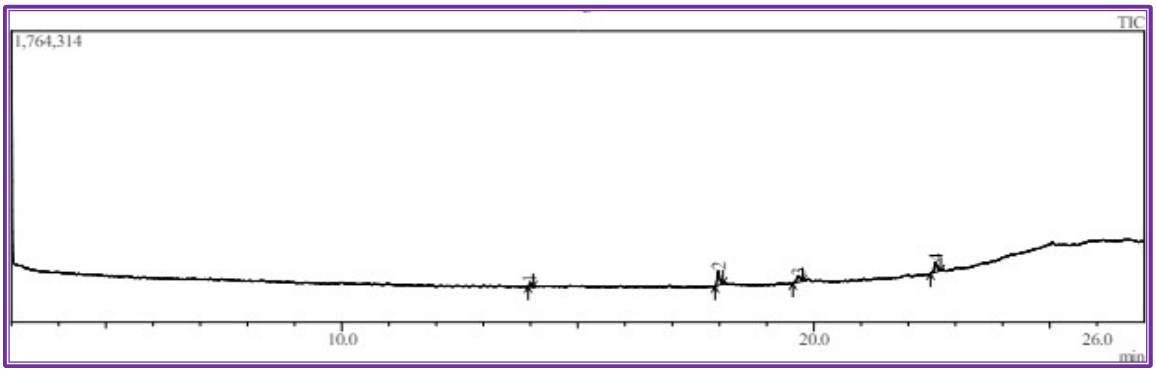


Figure 4: *Scanning Electron Micrographs Showing the Surface Morphology of LDPE Films After 90 Days of Incubation Without Bacterial Isolate (A-C), And with Bacterial Isolates Acinetobacter Bereziniae PD6 (D-F), Staphylococcus Epidermidis PD9 (G-I) AndBacillusCereusPD13 (J-L) (100µm, 20µm,5µm)*

GC-MS Analysis of Polyethylene

GC–MS analysis of diethyl ether extracts from LDPE films after bacterial treatment identified several intermediate compounds, including n-hexadecanoic acid, 2,2H-2,4a-methanonaphthalen-8(5H)-one, diethyl phthalate, nonanal, 6-octadecenoic acid (Z)-, palmitic acid 9-hexadecenyl ester (Z)-, oleic acid, bis(2-ethylhexyl) phthalate, and decanedioic acid bis(2-ethylhexyl) ester (Figure 5(a),(b),(c),(d)). The detection of these compounds indicates the formation of lower molecular weight oxidation and breakdown products following incubation with the bacterial isolates.



(a)

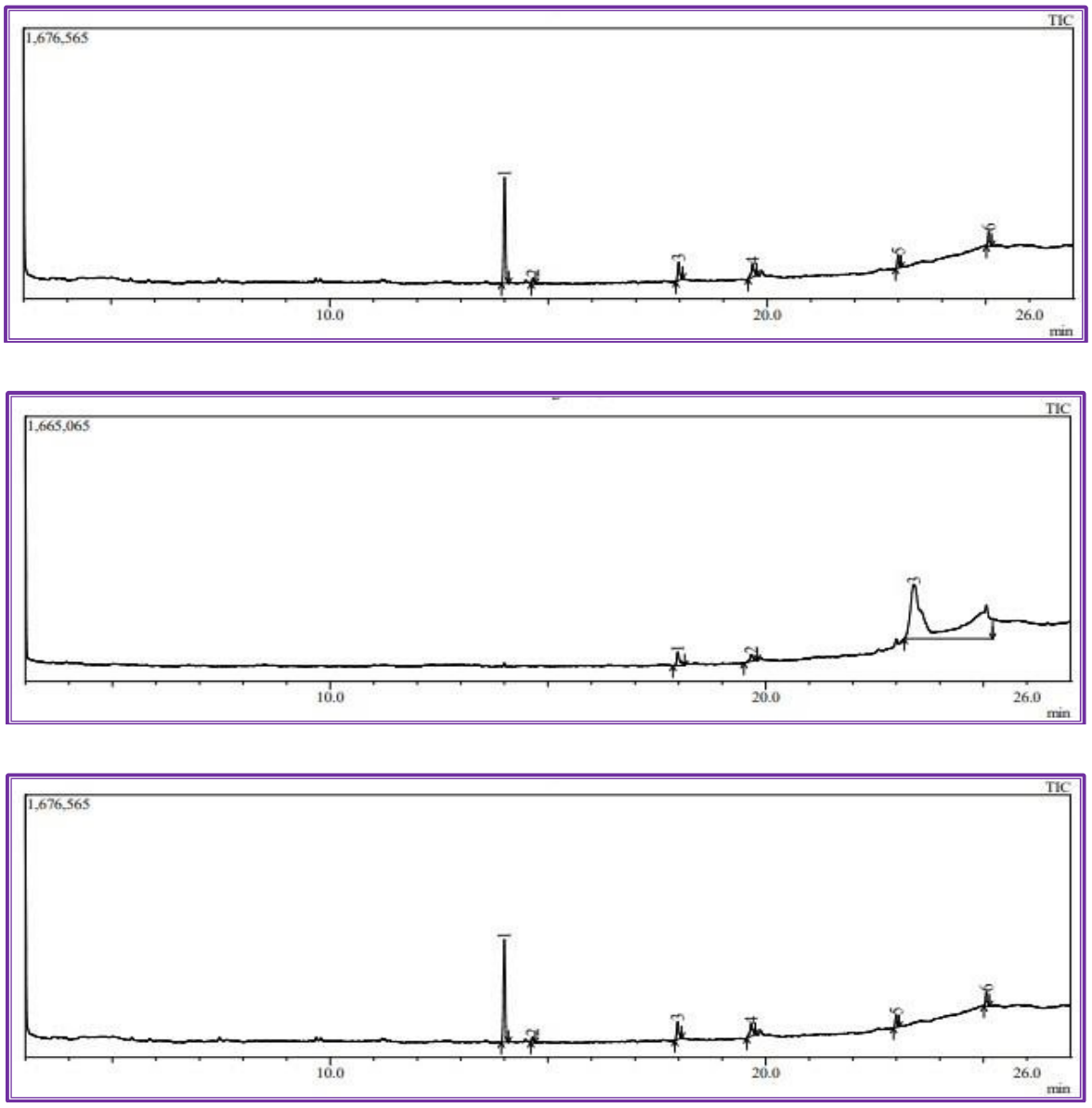


Figure 5: *GC-MS Analysis of Degradation Products of(A)Untreated LDPE and Treated LDPE(B)–Acinetobacter bereziniae (C)Staphylococcus epidermidis (D) Bacillus cereus*

Discussion

LDPE is widely distributed in the environment, and its persistent presence may promote the adaptation of certain microbial populations to utilize polyethylene as a potential carbon source. In the present study, three bacterial isolates, such as *Acinetobacter bereziniae* (PD6), *Staphylococcus epidermidis* (PD9) and *Bacillus cereus* (PD13), were obtained from long-term plastic landfill sites with confirmed LDPE-degrading capability, as evidenced by clear zone formation after incubation. Previous studies have reported the involvement of *Bacillus cereus* and *Staphylococcus epidermidis* in the biodegradation of LDPE and other hydrocarbons (Jebashalomi *et al*., 2024; Chatterjee *et al*., 2010), supporting the present findings. In addition, several species belonging to the genus *Acinetobacter* (Wang *et al.,* 2020; Kim *et al*., 2023; Zhang *et al.,* 2023; Kim *et al., 2024;* Ogunjemite *et al.,* 2025; Xia *et al.,* 2025) have been reported as potential plastic degraders. However, *Acinetobacter bereziniae* isolated in this study has not been reported to have the same ability, implying that such competency is a new discovery. *A. bereziniae* has evolved to develop the ability to utilize LDPE as an external carbon source found in the long-term plastic landfill area where plastic has been dumped for more than 10 years. Several studies

report that prolonged plastic accumulation can enhance soil microbial activity by providing an additional carbon source that microorganisms are able to utilize (Zhou *et al*., 2021; Wu *et al*., 2022).

Globally, approximately 286 bacterial species with plastic-degrading capabilities have been reported, distributed across only five major phyla—Proteobacteria, Actinobacteria, Firmicutes, Bacteroidetes, and Cyanobacteria—out of 31 phyla listed in the NCBI taxonomy database (Gambarini *et al*., 2021). The present investigation aligns with this trend, with identified degraders belonging to Firmicutes and Proteobacteria, two of the most commonly reported phyla associated with plastic biodegradation (Figure 1).

The identified bacterial isolates were assessed for their degradation potential, which was quantitatively determined based on the percentage of substrate weight loss. The reduction in LDPE film weight confirms the degradative potential of all three bacterial isolates, with *Acinetobacter bereziniae* (PD6) showing the highest level of weight loss, followed by *Bacillus cereus* (PD13) and *Staphylococcus epidermidis* (PD9) (Table 2). Although the percentage reduction was relatively low, such changes are consistent with early-stage polyethylene biodegradation reported in other *Acinetobacter* species (Lyu *et al*., 2024), *Bacillus* species (Isha & Chang,2024) and *Staphylococcus* (Shah *et al.,* 2026), though not previously documented for this species. The absence of weight loss in the uninoculated control confirms that the reduction resulted from microbial activity rather than abiotic factors.

FTIR analysis further supported structural modification of LDPE. Gulmine *et al*. (2002) reported that distinct FT-IR peaks for pure LDPE at approximately 2919, 2851, 1473, 1377, and 720 cm^{-1}, attributed to CH_2 stretching vibrations, bending deformations, and C–H bending modes. The control LDPE spectrum obtained in the present study showed comparable characteristic bands, confirming the typical structural profile of LDPE prior to treatment. The emergence of a new peak at 2960 cm^{-1} in all treated samples indicates chemical modification of the polymer backbone, suggesting the formation or increased exposure of –CH related groups during microbial action. Differences in peak intensity among isolates reflect variation in degradation efficiency, with *Acinetobacter bereziniae* (PD6) showing the strongest effect followed by *Bacillus cereus* (PD13) and *Staphylococcus epidermidis* (PD9). The reduced transmittance at 1745 cm^{-1} further suggests increased formation or transformation of carbonyl-containing groups such as ketones, which are commonly associated with oxidative degradation of polyethylene. Together, these spectral changes support the occurrence of isolate-mediated LDPE biodegradation (Figures 2 & 3).

SEM analysis of LDPE films treated with bacterial isolates revealed clear structural variations in the micrographs. These observations are suggestive of the disintegration of the smooth LDPE surface and the formation of pits, cavities, cracks, erosion and roughness (Figure 4). Such features may be associated with the non-uniform distribution of short branches in the polymer matrix, which can facilitate bacterial penetration during degradation (Manzur *et al*., 2004). Surface erosion is considered a major contributor to mass loss in polymer films undergoing biodegradation (Gajendiran *et al*., 2016). The observed surface alterations also suggest that bacterial cells are capable of colonizing and adhering to LDPE films, likely through extracellular polymeric substances, primarily polysaccharides (Raut *et al*., 2015). The presence of scattered whitened regions and erosion zones further supports a surface-erosion mechanism, possibly driven by enzyme-catalyzed reactions (Bhatia *et al*., 2014). Although the precise mechanism of LDPE degradation requires further investigation, it is generally believed to involve sequential enzymatic solubilization steps (Kyaw *et al*., 2012). The present findings are consistent with earlier reports on bacterial polyethylene biodegradation efficiency (Negi *et al*., 2009).

The GC–MS profile of LDPE samples degraded by the bacterial isolates showed several degradation products, including alcohols, esters, and ketones, indicating metabolic transformation of the polymer (Figure 5). During the decomposition of polyethylene or polypropylene, depolymerization can generate alkane intermediates through enzymatic activity, such as that of alkane hydroxylases, which are subsequently metabolized by microorganisms via β-oxidation pathways (Ji *et al*., 2013). Previous studies have also reported the formation of aldehydes, ketones, and carboxylic acids during LDPE processing and breakdown, as observed in extrusion coating emissions (Andersson *et al*., 2002). The

identification of fatty acids, aldehydes, and ester derivatives in the present study supports the occurrence of oxidative and enzymatic degradation of LDPE by the tested bacterial strains.

Limitations

These results indicate that isolates have promising polyethylene-degrading capability. However, a constraint of the present study is that LDPE degradation was evaluated mainly using gravimetric measurements and supporting analytical methods, without directly identifying or measuring the enzymes and metabolic pathways involved in polymer breakdown. Therefore, the exact molecular mechanisms used by these strains are not yet clearly understood.

Future Scope

Future studies should focus on isolating and characterizing responsible enzymes, along with genomic and proteomic analyses, to better explain the degradation pathways and improve efficiency. In addition, optimizing operating conditions and testing defined microbial consortia under real environmental conditions may further enhance degradation and support large-scale applications.

Conclusion

Developing sustainable, biologically based approaches is crucial for addressing the growing problem of plastic pollution. This study highlighted the degradation of LDPE films using newly isolated bacterial strains obtained from long-term plastic landfill soils, which are adapted to plastic-rich environments and exhibit enhanced ability to utilize polyethylene as their sole carbon source. In such environments, polyethylene serves as the primary carbon source due to limited availability of other nutrients, promoting microbial adaptation and polymer degradation. Among the isolates, the novel strain *Acinetobacter bereziniae* (PD6) showed the highest efficiency in degrading LDPE films, followed by *Bacillus cereus* (PD13) and *Staphylococcus epidermidis* (PD9). The biodegradation was confirmed through weight reduction analysis, FTIR spectroscopy indicating changes in functional groups, SEM analysis revealing structural alterations on the film surface, and GC–MS analysis identifying degradation products. The degradation efficiency of the bacterial strains could be due to the presence of enzymes that lead to the breakage of bonds in the polymer and its assimilation. Future studies should focus on the mechanisms of polyethylene biodegradation and the various factors that can improve the biodegradability characteristics of these isolated bacterial strains. This research has further scope to identify more microbial communities and the formulation of effective consortia that have the superior ability of biodegradation of plastic wastes.

Conflict of Interest

The authors declare that they have no conflicting interest.

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