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Isolation of Polyethylene-Degrading Bacteria From Municipal Landfill Soil

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ABSTRACT

Polyethylene is among the most widely used plastics and one of the most persistent, and landfill soil is the place where much of it ends up. Because that soil also holds dense and varied microbial communities, it is a natural place to look for bacteria that can attack the polymer, and many reports describe isolates from such sites that appear to degrade polyethylene films. This narrative review asks what those reports establish. It draws on published work on polyethylene structure, oxidative breakdown, isolation from waste-impacted soil and the methods used to claim degradation, and it reports no new data from any landfill. The literature supports a cautious picture: abiotic weathering usually has to open the polymer before microbes can use it, biofilm formation is common, and a handful of genera recur among reported isolates. Yet much of the evidence rests on weight loss and surface imaging, which cannot separate consumption of the polymer backbone from loss of additives or growth on contaminants. Few studies include sterile and abiotic controls, label the carbon, or identify the enzymes involved. The review concludes that isolation from landfill soil is a sound starting point and that a convincing claim needs several independent lines of evidence, and it sets out what such a study would contain.

Keywords: Polyethylene; Biodegradation; Landfill soil; Bacterial isolation; Plastic waste; Biofilm; Narrative review

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Article Class: Narrative Review

1. Introduction

Polyethylene turns up in carrier bags, packaging film, pipes and agricultural sheeting, and it is among the most widely produced plastics in the world (1). Much of what is made is used briefly and then discarded, and a large share of that waste

ends up in landfills or leaks into the surrounding environment (1, 2). Recycling helps, but contamination and mixed polymer types limit what it can recover (3), and what remains is chemically stable and persists for a long time. That persistence is the reason the question matters to waste managers, who must decide what happens



to discarded film.

That persistence has made biological solutions attractive. Landfill soil is rich in organic matter, moisture and microbial life, and it also contains the polymer itself, so it seems a fair place to look for bacteria that have learned to use it (4, 5). Many studies follow that logic: soil is enriched with polyethylene film, bacteria are isolated, and the film is reported to lose weight or change its surface (6, 7).

The difficulty is that such results are easy to obtain and hard to interpret. A film can lose mass because additives leach out, because it breaks into pieces that are washed away, or because cells and their products are removed by cleaning, and none of these is consumption of the polymer chain (8, 9). This review therefore asks a narrow question: when bacteria are isolated from municipal landfill soil and said to degrade polyethylene, what do the published studies actually establish? The aim is to describe what an isolation study can and cannot show, not to rank organisms. We report no isolation work and no data from any particular landfill, and the review makes no claim about any one site.

2. Literature Review

2.1 Polyethylene as a Substrate

Polyethylene is a long chain of carbon-carbon bonds with almost no chemical handles for an enzyme to grip. It is hydrophobic, it has a high molecular weight, and in its more crystalline forms the chains are packed tightly (8, 10). Low-density material is more branched and less crystalline than high-density material, and most reports of bacterial action concern the former (11). Table 1 sets out the main types and what each implies for degradation.

Commercial film is never pure polymer. It carries antioxidants, fillers, slip agents and

sometimes pro-oxidant additives meant to speed fragmentation, and each of these complicates the reading of a result (9, 14). A pro-oxidant film that breaks apart in sunlight has not been consumed by anything; it has simply become smaller. A mass loss that disappears when additives are accounted for is not degradation of the polymer.

Table 1. Polyethylene types and features that bear on microbial attack.

Type	Structure	Consequence for degradation
LDPE	Branched, lower crystallinity	Most studied; amorphous regions open more readily (7, 8)
LLDPE	Short regular branches	Intermediate; fewer reports (8)
HDPE	Little branching, high crystallinity	Slowest to weather and colonise (10, 12)
Oxo-degradable	Pro-oxidant additive added	Fragments in light and heat; biological fate debated (13, 14)
Film with additives	Antioxidants, fillers, slip agents	Additives can confound mass-loss readings (9)

Note: Qualitative summary from the cited literature; crystallinity and branching vary by grade and are not quantified here.

2.2 Abiotic Weathering and Oxidative Attack

The best-supported route to biological breakdown begins with chemistry, not biology. Light, heat and oxygen introduce carbonyl and hydroxyl groups into the chain, lower its molecular weight and make the surface more wettable (10, 15). Only once fragments are small and oxidised do microorganisms seem able to take them up and metabolise them (9, 10). Early work with labelled polyethylene reported a very limited conversion of



polymer carbon to carbon dioxide by soil fungi (16), a picture repeated in later reviews (17, 18). Polymer that has been pre-oxidised behaves differently from polymer that has not.

Buried waste receives little light, so weathering there is slow (15, 19).

2.3 Bacteria and Enzymes Reported to Act on Polyethylene

A modest set of genera recurs in the literature. *Rhodococcus ruber* was shown to colonise polyethylene, form biofilm and alter the film (20), and later work pointed to a copper-binding laccase as one enzyme that may take part (21). A thermophilic *Brevibacillus* was reported to reduce the mass of polyethylene at elevated temperature (22). *Pseudomonas* isolates have been tested on low-density film, including in biofilm form (23, 24), and *Bacillus* isolates come from mangrove, marine and soil sources (12, 25). Table 2 gathers these reports.

Table 2. Bacterial groups reported to act on polyethylene and the kind of support offered.

Group	Source of isolate	Support offered
<i>Rhodococcus</i>	Soil enrichment	Laccase-type activity proposed (20, 21)
<i>Brevibacillus</i>	Compost, thermophilic	Mass loss and surface change (22)
<i>Pseudomonas</i>	Soil, biofilm studies	Film changes and biofilm work (23, 24)
<i>Bacillus</i>	Mangrove, marine, soil	Surface change and mass loss (12, 25)
<i>Enterobacter</i> and others	Insect gut	Reported activity; role of host debated (26, 27)
Marine isolates	Seawater, sediment	Film changes after incubation (28, 29)

Note: Listing a genus means that at least one study reported activity; it does not mean that the activity has been confirmed or generalises.

Insects added a twist: bacteria from the gut of wax moth larvae were reported to grow on polyethylene (26), and the larvae were reported to damage film (27), but whether bacteria or host drive the effect remained open.

Bacterial alkane hydroxylases oxidise long alkanes (30), but whether they act on a solid polymer, or only on short oxidised fragments, is not settled. The recent discovery of an enzyme that degrades poly(ethylene terephthalate) shows that a bacterium can evolve a route to a synthetic polymer (31, 32), yet the ester bonds of that polymer are far easier to cleave than the carbon-carbon backbone of polyethylene (33, 34).

2.4 Surfaces, Biofilms and Soil Context

Cells on a plastic surface sit in a biofilm matrix (35), and the plastisphere communities of marine debris show that a cell on a film is not necessarily eating it (36). Soil adds more variables. Microplastics alter soil structure and water relations, and in turn affect the microbes that live there (37, 38). Landfill leachate is a changing mixture (4), so an isolate may reflect local chemistry as much as any gift for degrading plastic. Enrichment itself selects for fast growers on whatever carbon is present, and culture-based methods recover only a minority of the organisms in a sample (39, 40). This is why the same genus can look promising in one report and unremarkable in the next.

3. Materials and Methods

3.1 Scope and Question

This is a narrative review. It asks what published studies show about the isolation of polyethylene-degrading bacteria from municipal landfill and similar waste-impacted soils, and how reliable the methods used to demonstrate degradation are. It does not report new experiments, and it does not draw on samples from any



named site.

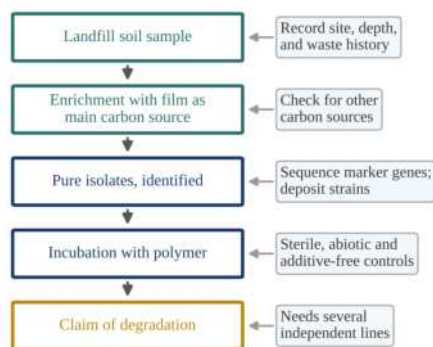


Figure 1. From soil sample to a claim of degradation, with the checks that belong at each step (schematic, not data).

3.2 Literature Assembly

Sources were gathered by reading, not by a formal systematic search. We began with major reviews of plastic biodegradation and followed their citations to primary studies, keeping works on polyethylene or on the methods used to judge it that were published in or before 2020. The selection reflects the authors' judgement, and relevant studies may have been missed. Reviews of this kind are more useful when they say where the evidence stops than when they smooth it over.

3.3 Appraisal Framework

Each reported claim of degradation was read against four questions. Was the substrate described, including additives and pretreatment? Were sterile and abiotic controls included? Did the evidence reach beyond mass loss and imaging? Was the organism identified and the activity attributed to it? These questions are simple. None of these steps is difficult, but each one is easy to skip. They were applied qualitatively, with no scores.

4. Results

4.1 How Isolation Studies Are Usually Built

Soil is suspended and spread on mineral medium with polyethylene film or powder

as the only added carbon; colonies are purified, identified and incubated with weighed film for weeks, after which the film is washed, dried and weighed again (6, 41). Figure 1 shows the sequence and the points where checks belong.

Anyone can run this design, but growth on mineral medium with film may rest on contaminants, on impurities in agar, on dead cells or on additives, and unless these are excluded the label of plastic degrader is premature (8, 42). Several authors have called for more rigorous practice in the field (5, 34). It is a habit worth keeping even when the answer seems obvious.

4.2 What the Evidence Can Support

Figure 2 arranges the steps of breakdown that a full account would have to cover. Weight loss is the commonest outcome measure, but it is the least specific. Electron microscopy shows pits and cells on the surface, which may arise from weathering alone (8, 15). Infrared spectroscopy can detect new carbonyl and hydroxyl bands and is a better sign of oxidation (10, 43).

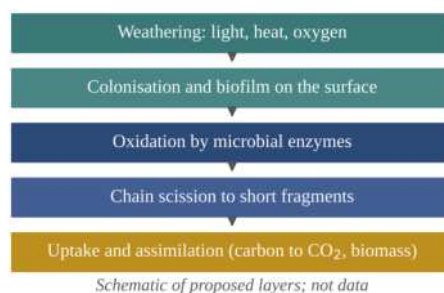


Figure 2. Proposed layers of polyethylene breakdown, from weathering to assimilation (schematic, not data).

Evidence that the polymer carbon itself has been consumed is scarcer. It requires labelled polymer, measurement of carbon dioxide against sterile controls, or a shift in the molecular weight distribution (16, 42). Table 3 lists these lines of evidence with their limits, and Figure 3 maps each onto



the question it answers. A reader of an isolation paper needs one answer above all: was the polymer itself consumed?

Table 3. Common lines of evidence for polyethylene degradation and their limits.

Evidence	What it shows	Main limit
Mass loss	Material disappeared	Additives, moisture and biofilm confound (8)
Electron microscopy	Pits, cracks, cells on surface	Can reflect abiotic weathering (15)
Infrared spectra	New carbonyl or hydroxyl bands	Shows oxidation, not who caused it (10, 43)
Carbon dioxide or label	Carbon reaches the gas phase	Needs labelled polymer; rarely done (16)
Molecular weight	Chains became shorter	Needs careful chromatography (42)
Enzyme or gene	A mechanism is named	Rare; hard to show on the solid (30, 44)

Note: Lines of evidence are those discussed in the cited methodological literature; none is sufficient alone.

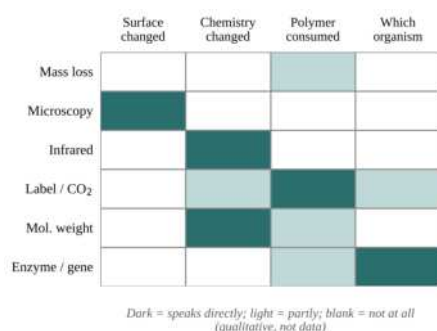


Figure 3. Which kinds of evidence speak to which questions (qualitative matrix, not data).

4.3 Patterns Across Studies

Three patterns stand out. First, reported rates are modest and incubations long, which fits slow attack on untreated polymer (7, 8). Second, the same few genera recur, partly because *Bacillus*, *Pseudomonas* and *Rhodococcus* grow readily in the laboratory (18, 44). Third, mixed cultures and co-cultures with fungi are often reported to do better than single strains (41, 45). Such differences are small individually, but they add up across a long

incubation.

Studies of dumpsite and landfill soils exist but are far fewer than those on marine or compost sources (6, 28). Marine isolates have altered polyethylene film in short incubations (28, 29), but transfer to buried waste is untested.

5. Discussion

5.1 Interpretation

Landfill soil is a reasonable place to look for polyethylene-degrading bacteria, and some isolates appear to alter films. But a change in film is not the same as consumption of the polymer, and the more rigorous the test, the fewer the claims that survive (8, 42). Enzyme-level explanations remain thin, and laccase and alkane-oxidising systems are plausible rather than demonstrated for the solid polymer (21, 30).

5.2 Limitations

Many studies are short, use a single film, report one measurement and omit sterile or abiotic controls. Isolates are sometimes identified from a partial gene sequence and rarely deposited for checking (17, 18). Films, media, temperatures and cleaning steps differ, so numbers cannot be pooled. Read this way, a null result from a short incubation is not evidence of absence.

This review has its own limits: it is narrative, not systematic, and its choice of sources is selective and unaudited. The point is not that a study is poor, only that its result travels less far than its abstract suggests.

5.3 Future Work

A convincing study would use well-described, additive-free polymer, include sterile and abiotic controls, and combine chemistry, molecular weight and carbon balance, ideally with labelled polymer (16, 42). It would deposit the strain and test whether activity survives



subculture and traces to a named enzyme (33, 34). Sampling several sites and depths, with records of waste age and leachate chemistry, would show what is typical (39, 40). Nothing in this reading argues against the search for plastic-degrading organisms; it argues for measuring what they actually do. These points apply with equal force to any other recalcitrant polymer, not only polyethylene.

6. Conclusion

Municipal landfill soil is a sensible hunting ground for bacteria that act on polyethylene, and published isolation studies have produced plausible candidates. They have not, in most cases, shown that the polymer is consumed. Weight loss and surface change are easy to measure and easy to misread, and the stronger evidence of labelled carbon, molecular weight and enzymes is scarce. The honest reading is that landfill isolates are leads, not solutions.

Future isolation studies need controls, several measurements and reporting detailed enough to repeat. Readers should ask of every claim what was measured and what was merely assumed.

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9. Conflict of Interest

The authors declare no conflict of interest.

10. Author Contributions

H.K. conceived the review and wrote the sections on polymer chemistry and the introduction. J.Z. wrote the sections on

microbial isolation and enzymes. P.V. wrote the sections on analytical methods and study design. All authors revised the manuscript and approved the final version.

11. Ethics Statement

This is a review of published literature. No human or animal subjects were involved and no ethical approval was required.

12. Data Availability

No new data were generated. All sources are cited in the reference list.

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