Unveiling the Power: Microbial Degradation by Plastic-Degrading Microorganisms

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Abstract

Plastics are more durable, flexile, cheap materials which are widely use in daily life. Different scientists have been reported harmful and adverse effects of plastics in terrestrial environments, marine ecosystem, human health, pollution in water, air etc. Nowadays degradation of plastics is become very friendly and economically beneficial by using various microorganisms like bacteria, fungi. This review of literature shows types of plastics based on their properties, uses of plastics in daily life and microorganisms used in degradation of plastic.

Keywords: Plastics, Bacteria, Fungi Biodegradation, Pollution

1. Introduction

Plastics are cheap petrochemical material, which are used in daily household ubiquitously (1,6). Plastic is more affordable, thermal, flexible, robust and electromagnetic insulator material (2). Plastics are widely used in construction material, food packaging packets, disposable cutleries, cassette disc because of its good properties and cheap cost (3). Plastic wastes are the good source of isolation of plastics degrading bacteria and that encode enzymatic activity to degrade plastic (4). Polyethylene is classified into mainly three categories: Low Density Polyethylene (LDPE), Linear Low-density Polyethylene (LLDPE), and High-Density Polyethylene (HDPE). Among them LDPE is widely used in daily households because of their extreme minimal weight and withstand lot before breaking down completely (5). Commonly used plastics are Polyethylene (LDPE, LLDPE, HDPE, MDPE), Polyethylene terephthalate (PET), Polybutylene terephthalate (PBT), nylon, Polypropylene (PP), Polysty rainy (PS), Polyvinyl chloride (PVC), Polyurethane (PUR) (5). According to recent study, ~ 60-70% of waste plastics are accumulated in landfills and the half life span of plastic degradation is ~10s-1000s of year (6). Because of slow degrading nature of plastic, it leads to obstruct to drain pipeline, air pollution, soil pollution, drain line blockage (7).

Basic steps of plastic degradations are: photo oxidation, thermos oxidative degradation and biodegradation. Among this biodegradation method is widely acceptable; in photo oxidation degradation, UV radiations are used, while thermos oxidative method is not used because of high thermal energy requirement (8). Plastic can be degraded also by aerobic, anaerobic and enzymatic methods that cleave the polymer plastic into monomer and oligomer (9). Biodegradation of plastic has been done by over 90 genera including bacteria, fungi: among them *Bacillus* sp., *Pseudomonas* sp., *Azotobacter* sp., etc., which cleave the polymer by enzymatic reaction and convert into monomer and oligomer (10, 11). The complete and finished plastic is non-toxic but, the monomer that is used for manufacturing of plastic is toxic (10,11,12). Degradation of plastic evaluated by weight loss, tensile strength loss, changed of polyethylene texture, changes in polyethylene chain molecular disturbance (13).

Because of non-degradability or slow degradability nature of plastic, the harmful effects occur on marine environments, wildlife animals, human lives, air pollution, terrestrial pollution (14). Recent microbial studies of ruminants found plastic objects from intestinal track of invertebrates, fish, birds, shows adverse physiological activities effect; also causes aesthetic problems (15).

1.1. Classification of Plastic

Based on thermal properties, designing properties and their degradation properties plastics are classed into various types. The types and applications are listed as below in Table 1:

Table 1. Types of Plastic and their applications

Sr. No.	Types of Plastic	Application	Reference
1.	Polyethylene Terephthalate [PET]	Drinking bottles, microwavable packaging, plastics films	16

2.	Polyurethane (PUR)	Synthetic foam	17
3.	Low Density Polyethylene (LDPE)	Plastic bags, bottles, disposable container	17
4.	High Density Polyethylene (HDPE)	Food and chemical packaging such as drinking bottles, motor oil bottles, detergent bottles	18
5.	Polyvinyl Chloride (PVC)	Artificial leather, construction material, pipes, packaging blends, toys, wire, pipes, cables,	19
6.	Polypropylene fibers	Pavements, floors, overlays, industrial slabs, shotcrete, tunnel linings	20
7.	Polystyrene (PS)	Commercial products such as disposal plastic cutlery, food containers, CD jewels, License, Insulators at low temperature, plates, petri plates, Laboratory equipment	5
8.	Polyurethane (PU)	Constituent material in many industries including furniture, coating, construction materials, fibers and paints	21
9.	Polycarbonate (PC)	Building construction, automotive and transportation, optical and ophthalmic media, medicine, packaging, optical data storage device	22
10.	Polyethylene	Bottles, carry bags, disposable articles, garbage containers, margarine tubes, milk jugs, water pipes	23
11.	Polylactic acid (PLA)	Biomedical filed such as material for sutures and bone fracture fixation, packaging	24

		material and mulching films	
12.	Polyester (PES)	Bottles, films, tarpaulin, sails, canoes, liquid crystal display, hologram, dielectric films	25
13.	Polyacrylamide (PAM)	Oil recovery, paper manufacturing, mining, as flocculants to improve sedimentation in sewage treatment	26
14.	Poly (butylene adipate -co-terephthalate) (PABT)	Production of blown films, and membrane products	27
15.	Poly [(2,2'-m-phenylene)-5,5'- dibenzimidazole] (PBI)	Aerospace industries	28

1.1.1 Classification based on thermal property of plastic

Based on thermal property of plastic, they are classified into two categories as: 1) Thermoplastic 2) Thermoset.

1.1.1.1 Thermoplastics

Thermoplastics are melted when heated and harden when cooled. Polyethylene terephthalate (PET), Polyethylene (PE). Low density polyethylene (LDPE), High density polyethylene (HDPE), Polystyrene (PS), Expanded polystyrene (EPS), Polyvinyl Chloride (PVC), Polycarbonate, Polylactic acid (PLA), Polypropylene (PP), Polyhydroxyalkanoates are the examples of thermoplastics.

1.1.1.2 Thermoset

Chemical structures can be changed when heated so cannot be remelted are known as thermoset. Polyurethane (PUR), Phenolic resins, Epoxy resins, silicone, vinyl ester, acrylic ester are examples of thermoset plastics.

1.1.2 Classification based on designing property of plastic

According their designing property of plastic, they are classified as electrical conductivity tensile strength, thermal stability, durability and degradability.

1.1.3 Classification based on degradability of plastics

Based on degradability nature, they are classified as degradable plastic and non-degradable plastic. Non-degradable polymer are synthetic and repeated units of its monomer. Degradable polymers are made up of starch.

2. Microorganisms involved in Plastic degradation

The role of Microorganisms in plastic degradation is very important. The different types of microorganisms have ability to degrade different groups of plastics. Table 2 shows different types of microbes have ability to degrade different types of plastic.

Table 2. Types of Plastic, microorganisms and their efficiency to degrade polyethylene

Type of Microbe	Type of Plastic	Source of Plastic	Degradation Efficiency	Reference
B. siamensis	LDPE	Soil of waste disposal site	8.46 ± 0.3%	29
B. cereus	LDPE	Soil of waste disposal site	6.33±0.2%	29
B. wiedmannii	LDPE	Soil of waste disposal site	5.39 ± 0.3%	29
B. subtilis	LDPE	Soil of waste disposal site	3.75± 0.1%	29
p. aeruginosa	LDPE	Soil of waste disposal site	1.15± 0.1%	29
Bacillus sp.	LDPE	Petroleum soil	23%	30
Fusarium sp. II	LDPE	Petroleum soil	44%	30
***B. siamensis* BS 10L**	LDPE	Soil	13.40± 0.013%	31
***B. siamensis* Plasma treated BS 10L**	LDPE	Soil	27.78±0.014%	31

Fussarium sp.	HDPE	Soil	2.65 %	32
Staphylococcus aureus	PE	Dumpsite Lagos	25%	33
Streptococcus sp.	PE	Dumpsite Lagos	31.2 %	33
Bacillus sp.	PE	Dumpsite Lagos	25 %	33
Micrococcus sp.	PE	Dumpsite Lagos	31.2 %	33
Bacillus safensis	LDPE	Pure culture media	18.6 %	34
Bacillus amyloliquefaciens	LDPE	Pure culture media	18 %	34
E. coli	PVC	Dump sol with plastic	5.32%	35
Pseudomonas sp.	PVC	Dump sol with plastic	40.53 %	35
Klebsiella	PVC	Dump sol with plastic	23.06 %	35
Staphylococcus	PVC	Dump sol with plastic	10.92 %	35
Aspergillus Niger	LDPE	Garbage soil	26.17 %	36
Aspergillus flavus	LDPE	Garbage soil	16.45 %	36
Streptomyces sp	LDPE	Garbage soil	46.7 %	36

2.1 Bacteria

Rodococcus ruber strain C208 has been isolated and have high degradation ability (37). *Pseudomonas putida* isolated from garden soil samples (38). *Bacillus licheniformis, Pseudomonas cereus, Pseudomonas putida, Bacillus subtilis, Bacillus cereus* was isolated from citrus mealybug by degradation of chlorpyriphos and polyethylene by endosymbiotic bacteria (39). *Acinetobacter guillouiae* was isolated from novel screening method using redox indicator (40). Polyethylene degrading bacteria, *Klebsiella pneumoniae* Mk-1 was isolated from soil sample (41). In addition, *Pseudomonas aeruginosa* strain SKN1 and SKN2 were isolated from waste landfill which have ability to degrade low density polyethylene bacteria (42). *Bacillus weihenstephanensis* were isolated from garbage soil which have ability to degrade LDPE and HDPE (43). *Kocuria kristinae, Dermacoccus nishinomiyaensis, Pseudomonas stutzeri, Acinetobacter haemolyticus* were isolated from payatus dumpsite, which have ability to degrade polyethylene Glycol and Low-density polyethylene (44).

2.2 Fungi

Mortierella sp., Doratomyces microspores, Fusarium solani, Fennellomyces sp., Aspergillus fumigatus, Verticillium sp., Lecanicillium saksenae, Cladosporium sp., Trichoderma sp., were isolated from soil and compost which have ability to degrade Poly (lactic acid) (PLA) (45). *Fussarium oxysporum, Fussarium falciforme, Purpureocillum lilacinum* fungi were isolated from dumpsite and have ability to degrade low density polyethylene (46). *Penicillium simplicissium* fungi was isolated from local dumpsite and have ability to degrade polyethylene (47). *Aspergillus clavatus* strain JASK1 was isolated from landfill soil which degrade low density polyethylene (48). *Aspergillus niger, Aspergillus flavus, Penicillium sp., white rot and brown rot* fungi were isolated from waste disposal site which have ability to degrade low density polyethylene bags (49). *Fusarium oxysporum, Aspergillus fumigatus, Lasiodiplodia crassispora, Aspergillus niger, Penicillium sp., Tricoderma harzianum* were isolated and screened of polyurethane (PU) and low-density polyethylene (LDPE) degrading soil fungi from municipal solid waste (50).

Acknowledgements

I am thankful to Dr. Pradeep Verma, Dean; Faculty of Science for providing the lab facility for performing my research work. I am also thankful to all the higher authorities of Swaminarayan University for their continuous support. I am also thankful to all Faculty of Science, Swaminarayan University, for supporting and motivating me for this work.

References

1. Akhigbe, G. E., EnochOghene, A. E., Olumurewa, K. O., Koleoso, O., & Ogbonna, N. D. (2022). Charatacterization of low density polyethyelene (LDPE) films degraded using bacteria strains isolated from oil contaminated soil. *RESEARCH SQUARE* , 1-13.

2. Mahitha, S., Premila, J. M., & Chelliah, D. A. (2022). Screening, identification and characterization of polyhydroxybutyrate producing bacyeria from garden soil. *RESEACH SQUARE*.

3. Ugueri, U., Atuanya2, E. I., & Usman, Z. (2020). Biodegradability of Polystyrene plastics by bacterial isolates from plastic composted waste soil and molecular characterization of plastic degrading bacterial isolates . *African Journal of Microbiology Research*, 247-257.

4. Howard, S. A., Carr, C. M., Sbahtu1, H. I., Onwukwe4, U., Lopez, M. J., Dobson, A. D., & McCarthy, R. R. (2023). Enrichment of native plastic associated biofil communities to enhance polyester degrading activity. *Environmental Microbiology published by applied microbiology international and John Willey & sons Ltd.*, 1-21.

5. Ghosh, T. (2023). Biodegrdation of Low Density Polyethylene (LDPE) by halophilic bacteria isolated from Bay of Bangal water. *ResearchGate*, 91-102.

6. Putman, L. I., Schaerer, L. G., Wu, R., Khulas, D. G., Zolghadr, A., Ong, R. G., . . . Techtmann, S. M. (2023). Deconstrated Plastic substarte prefrences of microbial populations from the Natural Environment. *Microbiology Spectrum*.

7. Mallisetty, R., Veluru, S., Hamzah, H. T., Hamem, M. N., Tukarambai, M., Poiba, V. R., . . . Mahdi, H. S. (2023). Biodegradation of low density polyethylene (LDPE) by Paenibacillus sp. and Serratia sp. isolated from marine soil sample. *Research Gate*.

8. KambleAsmita, Shubhamsingh, T., & Tejashree, S. (2015). isolation of plastic degrading microorganisms from soil sample collected at various locations in Mumbai, India. *International Research Journal of Environment Science*, 77-85.

9. Hussein, A. A., Al-Mayaly, I. K., & Khudeir, S. H. (2015). Isolation, Screening and Identification of low density polyethylene (LDPE) degrading bacteria from contaminated soil with plastic wastes. *Mesopotamia Environmental Journal* , 1-14.

10. sharma, J., Gurung, T., Upadhyay, A., Nandy, K., Agnihotri, P., & Mitra, A. K. (2014). Isolation and Characterization of plastic degrading bacteria from the dumping grounds of an Industrial area. *International Journal of Advanced and Innovative Research*.

11. Agustien, A., Jannah, M., & Djamaan, A. (2016). Screening polywthylene synthetic plastic degrading bacteria from soil. *Scholar Research Library*, 183-186.

12. Vignesh, R., Charu, D. R., Manigandan, P., & Janani, R. (2016). Screening of plastic degrading microbes from various dumped soil samples. *International Research Journal of Engineering and Technology*, 2493-2498.

13. S., D., & Subhashini, A. (2016). Screening and isolation of polyethylene degrading bacteria from various soil environment. *Journal of Environmental Science, Toxicology and Food Technology*, 1-7.

14. AsanousiLamma, O., Abdulnaser, F. T., & Alfaytouri Saeid, A. A. (2022). Screening of plastic degradng bacteria from dumped soil area: Astudy. *International Journal of Fuana and Biological studies*, 58-64.

15. Nadeem, H., Alia, K. B., Muneer, F., Rasul, I., Siddique, M. H., Azeem, F., & Zubair, M. (2021). Isolation and identification of low-density polyethyelene degrading novel bacterial strain. *Archives of Microbiology*.

16. Maciel, A. L., Nielson, T. K., Jensen, K., Nicolaisen, M. H., & Hennessy, R. (2023). Complete genome Sequence of Sphingopyxis sp. strain PET50, a potential Polyethyelene terephthalate (PET) degrading Bacterium isolated from Compost. *Microbiology resorce Announcement*.

17. Roy, R., Mukherjee, G., Gupta, A. D., Tribedi, P., & Sil, A. (2021). Isolation of soil bacterium for remediation of polyurethane and low-density polyethylene: a promising tool towardssustainable cleanup the environment. *3 biotechnology*.

18. Malyut, D. A., Matteson , K. I., Ryan , C., Berry, M. P., & Bajwa, D. (2023). An investigation into the tensile properties od rechycled High density polyethylene (rHDPE) blanded with talc filler. *Elsvier*.

19. Wang, F., Pan , S., Zhang, P., Fan, P., Chen, Y., & Yan, J. (2018). Synthesis and Application of Phophorus-containing Flame Retardant Plasticizer for polyvinyl chloride. *Fibers and Polymers*, 1057-1063.

20. Behfarnia, K., & Behravan, A. (2013). Application of High performance polypropylene fibers in concrete lining of water tunnels. *Matreial and Design*.

21. Ziaullah, S., Krumholz, L., Aktas, D. A., Hasan, F., Khattak, M., & Shah, A. A. (2013). degradation of polyester polyurathene by a newly isolated soil bacterium, Bacillus subtillus stain MZA-75. *Biodegradation* , 865-877.

22. WenlongYue, Chao-fan , Y., Sun, L., Zhang, J., XU, Y., & Zhou, N.-Y. (2021). Biodegradation of biophenol-A polycarbonate plasric by Pseudoxanthomonas sp. strain NyZ600. *Journal of hazardous materia* .

23. Begum, M. A., Varalakshmi, B., & Umamagheswari, K. (2015). Biodegradation of polyethene bag using bacteria isolated from soil . *International Journal of Current Microbiology and Applied Sciences*, 674-680.

24. Decorosi, F., Exana , M. L., Pini, F., & Adessi, A. (2019). The degradative capabilities of new Amycolatopsiisolates on polylactic acid. *Microorganisms*.

25. Sriyapai, P., Chansiri, K., & Sriyapai, T. (2018). Isolation and characterization of polyester based plastics- degrading bacteria from compost soil. *Microiology*, 290-300.

26. Yu, F., Ruimin, F., Yun, X., & Wuling, C. (2015). Isolation and characterization of polyacrylamide -degrading bacteria from dewatered sludge. *International Journal of Research and Public Health*, 4214-4230.

27. Weng, Y.-X., Jin, Y.-J., Meng, Q.-Y., Wang, L., & Zhang, M. (2013). Biodegradation behavior of Poly (Butylene adipate-co-terepthalate) (PABT) Poly (lactic acid) (PLA), and their blend under soil conditions . *Polymer testing*, 918-926.

28. Musto, P., Karaszt, F. E., & MacKnight, W. J. (1993). Fourier transform infra redspectroscopy on the thermo oxidative degradation of polybenzimidazole and of a polybenzimidazole/polyetherimide blend. *polymer*.

29. Maroof, L., Khan, I., Yoo, H. S., Kim, S., Park, H.-t., Ahmad, B., & Azam, S. (2020). Identification and characterization of low density polyethylene degrading bacteria isolated from soils of waste disposal sites. *Environmental Engineering Research*.

30. Vignesh, R., Deepika, R. C., Manigandan, P., & Janani, R. (2016). Screening of plastic degrading microbes from various dumped soil sample. *International Research Journal of Engineering and Technology*, 2493-2498.

31. Ji, S. H., Seungryul, Y., Seungil , P., & Mi, J. L. (2023). Biodegradation of loe density polyethyelene by plasma activatedBacillusstrain. *Elseiver*.

32. Rani, A., Singh, P., & Kumar, R. (2020). Microbial detoriation of high density polyethylene by selected microorganisms. *Journal of applied biology and biotechnology*, 64-66.

33. Akerele, H. A., Akinyemi, P. O., & Igbogbo - Ekpunobi2, O. E. (2022). Isolation and Identification of plastic degrading bacteria from dumpsite Lagos. *Advances in Environmental Technology*, 59-71.

34. Waqas, M., Muhammad, H., Noreen, A., Islam, H. u., Abdullah, A., Khan, A., . . . Sarfaraz, A. (2021). Biodegradation potential of Bacillus amyloliquefaciens and Bacillus safensis using low density polyethyelene thermoplastic substrate. *European Journal of Envrironment and Public Health*.

35. kumar, S., Teotia, U., & Singh, Y. (2017). Screening of polyvinyl chloride bacteria from plastic contaminated area of Baddi. *Journal of applied pharmaceutical research* , 34-37.

36. S, D., & Jaya, M. R. (2015). Biodegradation of low density polyethylene by microorganisms from garbage soil. *Journal of Experimental Biology and Agricultural Sciences*, 15-21.

37. Sivan, A., M , S., & Pavlov, V. (2006). Biofilm development of the polyethylene degrading bacterium Rodococcus ruber. *Applied Microbiology and Biotechnology* , 346-352.

38. Saminathan, P., Sripriya, A., Kaliappan, N., Thangavelu, s., & Veerapandiyan, T. (2014). Biodegradation of plastics by Pseudomonas putida isolated from garden soil samples. *Journal of advanced Botany and Zoology*.

39. Ibrahim, S., Gupta, R., War, A. R., Hussain, B., Kumar, A., Sofi, T., . . . Darwish, H. (2021). Degradation of chlorpyriphos and polyethylene by endosymbiotic bacteria from citrus mealybud. *Saudi Journal of Biological Sciences*, 3214-3224.

40. Kim, H. R., Chaerin, L., Shin Hyeyoung, Jongwon Kim, & Mija Jong. (2023). Isolation of Polyethylene degrading bacterium, Acinetobacter guillouiae, using a novel screening method based on redox indicator. *Heliyon*.

41. Zhang, X., Xu Feng, Yaun Lie, Hongmei Gou, Yao Zhang, & Lijuang Yung. (2023). Degradation of Polyethylene by Klabsiella pneumoniae Mk 1isolated from soil . *Ecotoxicology and Environmental Safety*.

42. Nourollahi, A., Samaneh, S.-k., Mehdi, M., & Gilda, E. (2019). Isolation and identification of low density polyethylene (LDPE) degrading bacteria from waste landfills in Yazd. *Internal Journal of Environmental Sciences*, 236-250.

43. Ingavale, R. R., & Raut, P. D. (2018). Comparative Biodegradtion studies of LDPE and HDPE using Bacillus weihenstephanensis isolated from garbage soil. *Nature Environmentand Pollution Technology*, 649-655.

44. Bolo, N. R., Diamos, M.-a. C., Glenn, S. L., Melody Melody, O. B., & Ocampo, O. M. (2015). Isolation, Identification and Evaluataion of polyethylene Glycol and low density polyethylene degrading bacteria from payatus dumpsite, Quezon city, philipines. *Philipine Journal of Health Research and Deveopment*, 50-59.

45. Karamanlioglu, M., Houlden , A., & Robson, G. D. (2014). Isolation and characterization of fungal communities associated with degradation and growth on the surface of poly (lactic acid) (PLA) in soil and compost. *International Biodetoration and Biodegrdation*, 301-310.

46. spina, F., Maria, L. T., Anna, P., Valeria, P., Viktoria, I., Piersandro, C., . . . Giovanna, C. V. (2021). Low density polyethylene degradation by filamentous fungi. *Environmental POllution* .

47. Sowmya, H. V., Ramalingappa, Krishnappa, M., & Thippeswamy, B. (2015). Degradation of polyethylene by penicillium simplicisimum isolated from local dumpsite of Shivamogga district. *springer*, 731-745.

48. Gajendiran, A., Sharmila Krishnamoorthy, & Jayanthi Abraham. (2016). Microbial degradation of low density polyethylene (LDPE) by Aspergillus clavatus strain JASK1 isolated from landfill soil. *Biotechnology*.

49. Saira, Abdullah, Maroof, L., Madiha, I., Saira, F., Lubna, & Shah, F. (2022). Biodegradation of low density polyethylene (LDPE) bags by fungi isolated from waste disposal soil. *AApplied and Environmental soil Science*.

50. Raghavendra, V. B., U. M., 2Govindappa, Vasantha, M., & R A , 3. S. (2016). Screening and identification of polyurathane (PU) and low density polyethylene (LDPE) degrading soil fungi isolated from municipla solid waste. *International Journal of Current Research*, 34753-34761.