Poll Res. 40 (4) : 1273-1283 (2021)

ISSN 0257–8050

NATURAL DEGRADATION OF PLASTIC-A GREEN APPROACH : REVIEW

VENKATA KANAKA SRIVANI MADDALA

Department of Science and Humanities, VFSTR Deemed to be University, Vadlamudi 522 213, Guntur, India

(Received 12 February, 2021; accepted 22 April, 2021)

ABSTRACT

Plastic waste present in the environment lead to serious ecological threat. Improper recycling of plastic waste destroying marine and terrestrial environment today. Degradation of plastic by physical and chemical processes may prone to health hazard. Many companies adopted recycling and disposal of plastic to eradicate pollution but not up to the mark. So many ecofriendly methods have been developed to degrade the plastic waste some of them were bacteria, fungi and protists. This review highlights the effects of plastic pollution in terrestrial and marine environment, degradation of plastic waste by using microorganisms and throws light on ecofriendly plastic to reduce pollution and helps in sustainability

KEY WORDS : Introduction to plastic waste, Health risks, Biodegradation, Eco friendly plastics

INTRODUCTION

Plastics made from petrochemical materials. Polyethylene, polypropylene, polyvinylchloride, polystyrene, polyurethane, polysuccinate, polylactic acid, polybutylene succinate are used for various purposes and are non-degradable (Muhamad, *et al.*, 2015). Microorganism can be used as plastic biodegradation agent towards sustainable environment (Yoshida *et al*., 2016). Plastic waste is the cheap source of chemical energy and it can be obtained from discarded bottles, bags, drink lids, straws, pots, trays. Plastic is flexible, durable, cost effective, easy to handle and shows resistant towards corrosion.1.5 million tons of plastic waste is generated from 2.5 billion world population where as in the year 2016, 320 million tons of plastic generated from seven billion people and it may double in coming future. 40% of plastic comes from different packaging applications and increases by 12% per annum. 8.3 million tons of plastic discarded in the sea every year and causing threat to marine organisms. Plastic may be biodegradable and bio based plastics. Biodegradable plastics are degraded by microbes completely and hence ecofriendly. Bio based plastic are made from organic materials and biodegradable. They are ecofriendly materials and burned to produce carbon dioxide and that can be again converted in to biomass by photosynthesis (Iwata and Tadahisa, 2015). The larger plastic waste degrades and converts into micro plastics which has the size of 5mm in diameter.

The microplastics are of two types like primary with size of 2 mm and secondary microplastics with size of less than 1mm. Secondary microplastic are formed by thermal degradation, biodegradation, photo degradation and hydrolysis (Sharma *et al.* 2017). Primary microplastics are formed by chemical formulations and blasting (polyethylene and polystyrene). Different types of plastic wastes like nylon, polycarbonate, polyethylene–terephthalate, polypropylene, polystyrene, polyurethane, polyvinylchloride, polytetraflouro-tetraethylene were utilized regularly (Usha *et al.,* 2011). Even plastic is hazardous it has many advantages like maintenance of food safety, and quality reduces the wastage of food it also avoids contamination of food from moisture and easy to handle so almost all the people utilize plastic. Marine environment is also contaminated by plastic waste such as disposal of waste materials by tourists, fishing nets, aquaculture and nautical activities. It is non-biodegradable and even its difficult to eradicate in nature. Three hundred eighty-one million tons of plastic waste is generated on earth year wise.It persists in the environment for long time and acts as proof against microorganisms (Gilmore *et al.*, 2009). The main sources of plastic wastes come from industrial and domestic wastes and degrade the soil quality. The plastic consumption in India is eight million tons per annum and 5.7 million tons of plastic converted in to waste and creates problems year wise (Rathi, 2006). It is not possible to dispose the plastic waste using landfills (Aguado *et al.*, 2007). The most common plastics we use today are polyethylene, poly propylene, poly vinyl chloride, polystyrene, polyurethanes. In this paper we focused on impacts of plastic waste on environment biodegradation of plastics by microorganisms for sustainability.

Health risks of plastic waste

One of the biggest challenges faced today is the disposal of plastic waste that persists in soil for long time about 1000 years in environment. Methods like incineration, recycling and landfills are used for disposal but incineration releases harmful chemicals and greenhouse gases in environment and causes harmful diseases, recycling is difficult process and land filling is the best method but increase in the plastic created trouble. Plastic releases harmful chemicals in the environment by recycling. Many fishes die by ingesting the plastic in marine water (Boerger, 2010). On burning plastic waste releases harmful chemicals and effects respiratory systems, leads to Asthma, nausea, head ache and damages nervous system. Marine organisms especially sea turtles eat plastic considering them as jelly fish and leads to death (Derraik, 2002; Gregory, 2009). Zooplanktons, cetaceans, fishes and seabirds ingested plastic as the size of it is less than 5mm. 17% of marine species added in red list and other ten percent ingested plastics (Xanthos *et al.*, 2017). Top twenty countries in the world said that plastic waste from land is the main source for marine water pollution (Jambeck *et al.*, 2015). Many chemicals from plastic waste discharge upon ingestion and enters in to the body tissues (Ryan *et al.*, 1988). The consequences of plastic wastes are very high in countries like Taiwan (Walther, 2015), United Kingdom, Japan. The major current environmental problems are the accumulation of macroplastics and litter (Hartley *et al.*, 2018). Plastics fragments when exposed to UV radiations are damaged and broken down in to smaller and smaller fragments. Small fragments of plastic material can reduce its size persists in the environment as non-degradable (Roy *et al.*, 2011). Microplastics may enter in to the marine water and effects the Plankton population by reducing the absorption of chlorophyll or these plastic fragments retain in their tissues (Laist, 1987). Ingestion of microplastics by fish results in histopathological modification in the intestine that removes the epithelial lining from Laminopropia causes widening reduction and puffing of villi, globet cell number increases and changes in normal structure of serosa of fish (Cristina *et al.*, 2016). Plastic debris increased rapidly and may prone to cancer in many organisms including man. The main cause of cancer is bisphenol (BPA) which is used in the preparation of some plastics and resins. Results revealed that oestrogen mimic BPA results in mammary and prostate gland cancer (Maffini *et al.*, 2006). Application of polyethylene in packaging, retail industries and agricultural use release large number plastic waste on earth (Usha *et al.*, 2011). Thermophillic streptomycetes destroy PHB, PES, PBS, Poly oligotetramethylene succinate. But fungi Actinomycetes play a vital role in degrading PHB than thermophillicst reptomycetes (Calabia and Tokiwa, 2004). Burning of plastic is another practice that release harmful chemicals like furan, dioxins in to the air and causes environmental pollution and effects human endocrine hormonal activity (Pilz *et al.*, 2010a,b). Problems mainly occurred due to mismanaged plastic waste. Using toxic plastic waste can cause headache, lung infection, cancer, skin diseases, loss of vision, gastro intestinal diseases, birth defect, cardiovascular and reproductive diseases. Many of the researchers revealed that microplastic pollution is harmful to soil and terrestrial ecosystems (Liu *et al.*, 2016; Rochman *et al.*, 2015). According to Rillig, (2012) the plastics enters deep in to the soil by the action of earth worms. The fragments of plastics may combine with microplastic on the soil surface percolated deep into the soil by the action of insects, plants and collembolans (Maa ß *et al.*, 2017). Most of the plastic waste floats on the surface of sea water and reaches the land results in degradation. Plastic debris swallowed by some of the endangered species like California Congo (Mee *et al.*, 2007). It also effects the beauty of the place and causes hazard to maritime activities (fishing and tourism) Synthetic polymers in the marine environment: a rapidly increasing, long-term threat (Moore, 2008; Gregory, 2009). The plastic debris that floats on the surface of the water may colonize the marine organisms persists on the sea floor for long time and allow the transport of nonnative species (Barnes and Galgani, 2009). In US center for disease control study reported that 93% of the people tested BPA positive which is a harmful substance present in plastic products. According to (Zhu, Zho, 2013) the usage of Bisphenol A and other alkylphenols released in to the aquatic environment and their highest concentrations lead to toxicity and low concentrations disrupt the endocrine function in aquatic organisms and human beings in order to control all these effects. So many ecofriendly products called bioplastic was developed all over the world to use them for our daily needs

Biodegradation

Plastics are not degradable and leads to environmental pollution so the degradation of plastic waste is very important. However plastic waste can be used by converting it into oil and liquid through microporous and mesoporous catalysts (Uemichi *et al.*, 1998). According to Douglas Polystyrene which is a major environmental pollutant can be converted in to oligomer, monomer and other useful hydro carbon with highest energy efficiency by using Supercritical water partial oxidizing technology (SCWPO) (Lilac and Lee, 2001). Biodegradation of plastic waste gained attention today as it is environmental friendly and attain sustainability. Microorganisms are used to degrade the plastic waste which is ecofriendly. It is very difficult to degrade polyethylene by the use of microbes. Polyethylene with least molecular weight can be degraded by *Actinobacter* species. Poly ethylene can be degraded due to synergistic action of photo and thermo oxidation reactions. Some of the bacterial strains associated with *Pseudomonas* species *Rhodococcus erythropolis* (Koutny *et al.*, 2009) *Staphylococcus cohnii* (Nowak *et al.*, 2011). *Streptomyces badius* (Pometto, 1992). *Micrococcus luteus* (Nowak *et al.*, 2011). Micro bacterium paraoxydans (Rajandas *et al.,* 2012). Recent survey has shown that polyethylene can be used for degradation by using exoenzymes under stress conditions. Enzymes produced from *Acromobacter, Candida cylindracea*, *Rhizophus delemar*, *Rhizophus arrihizus* degrades Polyethylene adipate, Poly - caprolactone (Tokiwa *et al.*, 1976). Some of the fungal species that degrade different types of plastics (PBA, PPA, PCL, PVC, PHB, PU, PFA) are *Asperigillus, Fusarium, Mucor, Pencillium, Rhizophus, Chaetonium, Verticillium, Rhodosporidium*. PCS can be degraded by *Asperigillus fischeri, Asperigillus flavus* (Benedict *et al.*, 1983b). PVC can be degraded by bacteria like *Pseudomonas putida* (Danko *et al.*, 2004). *Pseudomonas fluorescens, Ochrobactrum* (Mogilnitskii *et al*., 1987). Polyester PUR can be degraded by various fungal species like *Aspergillus niger, Aflavus, Penicillium funiculosum, Trichiderma, Chaetomium globosum* (Darby and Kaplan, 1968). Pathirana (1984) found that Polyster PUR can be degraded by fungal species like *Gliocladium reseum, Chaetonium globosum, Pencillium citrinum, Aspergillus fumigates* (Pathirana and Seal, 1985b). Crabbe, 1994 found that fungal species like *Fusarium solani, Cladosporium* species, *Curvularia senegalensis* results in degradation of Polyster PUR (Crabbe *et al.*, 1994). It was also revealed that maximum polyster PUR can be degraded by *Cornybacterium* species B6, B12 and *Enterobacter agglomerans* B7 (Kay *et al.*, 1991). Microorganisms play a vital role in degradation of Polyethylene which are called synthetic polymers and widely used and their degradation is very slow and persist in nature for long time synthetic non degradable polymers can be degraded by using microorganisms (Gu *et al.*, 2003; Lee *et al.*, 1991). Polyethylene terephthalate is used in packaging and manufacturing beverage bottles that leads threat to environment (Webb *et al.,* 2013). So reduction of

Table 1. Types of Plastic waste and its life span

SNo.	Plastic	Life span in years
1	Water bottles	450
2	Plastic 6 pack collar	450
3	Disposal diapers	500
4	Polystyrene foam	5000
5	Plastic bags	10-20
6	Plastic straw	200
7	6 pack Plastic rings	400
8	Coffee cup	30
9	Coffee pod	500
10	Plastic cup	450
11	Plastic toothbrush	500
12	Foam plastic cups	50
13	Foam plastic buoy	80
14	Plastic water lines	50-75
15	Chlorinated poly vinyl chloride	50-75
16	Disposal nappies	450
17	Beer holders	450
18	Extruded polystyrene foam	5000

Table 2. Plastic and its degradation by microbes

S. No.	Name of the plastic	Degradation by bacteria	Degradation by fungi
	Polyethylene	*Rhodococcusrhodo chorus Rhodococcusruber* (Orr *et al*., 2004, Fontanella *et al*., 2010)	Cladosporioides fungus, *Aspergillus flavus* fungus
	Polyethylene	*Staphylococcus cohnii, Staphylococcus xylosus* (Nowak *et al*., 2011) *Staphylococcus epidermidis* (Chatterjee *et al*., 2010). *Nocardia asteroids Acinetobacterbaumannii*	*Aspergillus niger* and *Asperigillus japonica A. niger* degrades 5.8% of low density Polyethylene and *Asperigillus japonicus* degrades 11.11% of Polyethylene (Raaman *et al*., 2012 *Myceliophthora* species
	Polyethylene	*Pseudomonas* species, *Pseudomonas aeruginosa* (Rajandas *et al*., 2012) *Pseudomonas fluorescens* (Nowak *et al*., 2011) *Brevibaccillus borstelensis* degrades polyethylene on combination with photooxidation and also degrades CH2 back bone of non-irradiated polyethylene *Sphingomonas* used for polyethylene plastic samples	Produce an enzyme called Laccase can degrade plastic when this fungus grown with plastic waste Fungi Mucorrouxii (46.5% elongation reduction in fungi) and 60% elongation reduction in *Streptomycetes* species (El-Shafei *et al*., 1998)
	Polyethylene .	*Bacillus cereus, Bacillus mycoides, Bacillus thuringiensis* (Nowak *et al*., 2011).*Bacillus circulans, Bacillus halodentrificans* (Roy *et al*., 2008; Watanabe *et al*., 2009	*Verticilliumlecanii* (Karlsson *et al*., 1988)
	Standard oxidized PE	*Thermophillic bacterium* like *Brevibacillusborstelensis* (Hadad *et al*., 2005)	Actinomycetes *Rhodococcusrube*r Gilan *et al*., 2004; Sivan *et al*., 2006; Mor *et al*., 2008 *Penicillium simplicissimum* (Yamada *et al*., 2001)
	Plastic strips		*Aspergillus oryzae* Soil pits were made and plastic strips were buried in the pits and it is enriched with *A.oryza* and results revealed that the plastic strips were degraded by fungus (Indumathi *et al*., 2016)
	Polyester and Polyurethane	*Staphylococcus epidermidis* (KH11) but the degradation is slow degrades polyster PUR (Jansen *et al*., 1991)	*Aspergillus tubingensis* (Khan *et al*., 2017) *A flavus, A fumigatus, A.versicolar* degrades PUR polyether and PUR polyster (Darby *et al*., 1968) *Cladosporiumsps* degrades Polyster PUR (Crabbe *et al*., 1994).
	Polyethylene microplastics		*Zalerionmaritimum* (Paco *et al*., 2017)
	Poly(lactic acid)		Phanerochaete, *Chrysosporumfungus* (Stoleru *et al*., 2017.)
	Polyethylene(high or low density). Polypropylene and Polystyrene	Methylobactersps, Methylocystic species and Methylocellasps	

Table 2. Plastic and its degradation by microbes

S. No.	Name of the plastic	Degradation by bacteria	Degradation by fungi
	Poly butylene succinate		Strain from *Fusarium solani* (Abe *et al*., 2010).
	Polycaprolactone		*Penicillium* strain Degradation of high molecular weight of PCL and produce hydroxycaproic acid as degraded product Low molecular weight of PCL degrades by *Pullularia pullulans* completely degraded after twelve months (Fields *et al*., 1974)
	Polylactic acid (PLA)	Degradation of PLA by *Amycolatopsis, Lentzea, Kibdelosporangium, Streptoalloteichus, Saccharothrix*.	
	PLA, PCL, PBS, and PBSA	*Pseudomonas* and *Rhodococcus*	*Clonostachysrosea* and *Trichoderma*
	Plastics cups	*Micrococcus luteus* and *Masoneilla* species (Sivasankari *et al.,* 2014)	
	BTA co polyster Polymers	*Thermomons porafusca* *Pseudomonas fluorescens, Pseudomonas aeruginosa*	Kleeberg *et al.,* 1998 *Penicillium simplicissimum* (Rziyafathima *et al.,* 2016; Singh and Sharma, 2008).
	Polyethylene succinate	*Pseudomonas* species, AKS2 (Tribedi 2014). Thermophilic strain *Bacillus* species TTS (Tokiwa, 2009) Mesophilic strains *Bacillus* and *Paenibacill usgenera* (Tezuka *et al*., 2004; Tokiwa *et al*., 2009)	
	PET	Ideonellasakaiensis 201-F6 degrading non-biodegradable polymer PET	
	Polyethylene bags	Can be degraded by microalgae *Scenedesmus dimorphus*, (green microalgae), *Anabbaena spiroides* (blue green algae), and *Navicula pupula* (diatom) Kumar *et al.* (2017).	

plastic consumption and recycling of polymer materials help to curb plastic pollution and attain sustainability (Hopewell *et al.,* 2009). Most of the organisms die by swallowing the plastic waste or being caught in plastic waste traps and gets damaged (Usha *et al.,* 2011). Vinyl chloride is carcinogenic and causes cancer (Rudelruthann *et al.,* 2007) and Styrene leads to mammary gland tumors in animals and act as endocrine disrupter (Gray *et al.,* 2009) Polyster and Polyurethane can be degraded by *Staphylococcus epidermidis* and *Aspergillus tubingensis*. *A flavus, A fumigatus, A.versicolar*. Polyethylene microplastics can be degraded by *Zalerion maritimum*. Polycaprolactone by *Penicillium* strain. Degradation of high molecular weight of PCL produce hydroxycaproic acid as degraded product. Many methods were developed based on the research but still more technology is required to curb plastic waste. There is a new bacterial strain *Ideonella sakaiensis* 201-F6 play a vital role in degrading non-biodegradable polymer PET by using its energy and carbon source. The enzymes present in this strain hydrolyze PET and terephthalic acid in to harm less products (Yoshida *et al*., 2016). According to Kumar *et al*., 2017 micro algae like *Scenedesmus dimorphus*, (green microalgae), *Anabbaenaspiroides* (blue green algae), and Naviculapupula (diatom) dominant in degrading polythene bags (Kumar *et al.,* 2017).

Eco friendly plastic

It is very difficult to control plastic waste as many of the goods we use are made of plastic. Based on the research and development there are many environmental friendly plastics were developed and does not cause harm to the environment. Bioplastics are made from natural substances like corn starch and does not produce carbondioxide when it is broken down. They can be decomposed easily within weeks and compostable. Bioplastics are made from the plant waste here powders of fruits and vegetables were used to manufacture bioplastics and it becomes alternative for fossil derived plastics.

Biodegradable plastics consists of additives and made them to decompose easily in the presence of light and oxygen and they may leave toxic substances behind and prevents composting. Recycled plastics are the plastics made from old plastic materials by recycling and the same item cannot be generated. So many ecofriendly plastics like bamboo tooth brush, green bags, green bee wraps, reusable coffee cups, safety razors, Green bee wraps. Compostable bin liners from plants, Stasher Silicone Reusable Food storage ecofriendly and washable and can handle cold and hot temperatures, iPhone made up of flax, cork, green toys from milk jugs, plastic jugs from reclaimed milk jugs, instead of plastic wooden sunglasses and watches, bamboo fiber cloths instead of Microfiber towels for cleaning rooms can be used. Many

Table 3. Eco friendly plastic products to reduce plastic pollution

SNo	Eco friendly products	Plastic goods
1	Bamboo straws, paper straws, rose gold green straws	Plastic straws
2	Cotton buds from bamboo packed in recycled bags	Plastic ear buds
3	Corn starch and bamboo tooth brush	Plastic tooth brush
4	Green bags(with cloth/paper)	Polythene bags
5	Earth water bottle/double insulated stainless steel water bottles	Plastic water bottle
6	Bee green wraps(made with organic ingredients)	Plastic sandwich bags
7	Safety razors	Plastic razor
8	Reusable coffee cups	Plastic coffee cups
9	Steel lids	Plastic lids
10	Recycled rugs	Plastic rugs
11	Eco computer accessories(made from sustainable materials)	Plastic computer materials
12	Green toys	Plastic toys
13	Biodegradable garden pots	Plastic pots
14	Leaf ware compostable forks, spoons, knives	Plastic spoons, forks and knives
15	Eco friendly or compostable waste	Plastic wastes
16	Wooden sun glasses and wooden watches	Plastic glasses and watch
17	Compostable bin liners made from renewable plants (to prevent microplastic left)	Plastic bin liners
18	Stasher Silicone Reusable Food storage ecofriendly and washable and can handle cold and hot temperatures)	Plastic bag
19	Sqwishful sponges (made up of plant based cellulose)	Polyurethane sponge
20	Eco friendly i phone II case (made up of flax, cork and recycled bottles-bioplastic)	i Phone case plastic
21	Wooden or disposal utensils	Plastic utensils
22	Sugarcane fiber plates (compostable and biodegradable)	Plastic plates
23	Reusable baby food pouch	Plastic pouch
24	Computer accessories from sustainable materials	Plastic computer accessories
25	Green toys from recycled milk jugs and recycled plastic	Plastic toys
26	Recycled plastic chairs made from reclaimed milk jugs	Plastic chairs
27	Ecofreindly bottles made from plants(the natural sugars in plants converts in to material used to make PET plastic bottles	Plastic bottles in coca- cola, Pepsi and Nestle industries
28	Bamboo fiber cloths	Microfiber towels for cleaning rooms

ecofriendly innovative instead of plastic were developed based on the technology to curb the problem but even though the problem continued due to lack of individual participation in the society. Innovatives like compostable pizza boxes and biodegradable packaging vessels are used. Many plant based products are used for packaging of food and take away containers to control harmful effects in environment.

Bioplastic pet food packaging

This package consists of 30% of bioplastic and can reduce carbo foot prints. The material used for food packaging is made from ethanol of Brazilian sugar cane (https://www.trendhunter.com/slideshow/ecofriendly-packaging-innovations). Compostable sea weed based sauce sachets are the innovative made to reduce plastic waste. This can be used and easily decomposed with in six months so we can discard them easily (used against plastic packing). Green plastics called green polyethylene made from sugar cane derived ethanol mitigate climate change. It is made from renewable resource and each Kilo of green plastics can capture 3.09 kilos of carbon dioxide (de Vargas mores, Giana *et al.,* 2018). Instead of plastic wood plastic composite are used. They consists of plant fibers and thermoplastics which are biodegradable and renewable and used in constructional activities, buildings and furniture (Panthapulakkal *et al.,* 2006. Preparation and characterization of wheat straw fibers for reinforcing application in injection molded thermoplastic composites. Green packaging helps in sustainability as they can be degraded by microorganisms. Green packing materials are biodegradable composite materials having unique properties compared to petrochemical based plastics and they show 100% degradation (Youssef, Ahmad *et al.,* 2019; Youssef, Ahmad *et al.,* 2018).

These are some of daily usage plastic items in residential areas

CONCLUSION

Even today utilization of plastic waste is continued and troubling our earth. There is a need to do more research on degradation of plastic waste. Novel innovative methods must be developed for conservation of nature and ecosystem against the harmful plastics. Creating awareness about the effects of micro plastic. Collection and reuse of plastic fragments helps to reduce stress on ecosystems. Many methods were developed to degrade the harmful plastic further more research is

Fig. 1. Polythene in residential areas

Fig. 2. Plastic bottles

Fig. 3. Plastic cool drink bottles

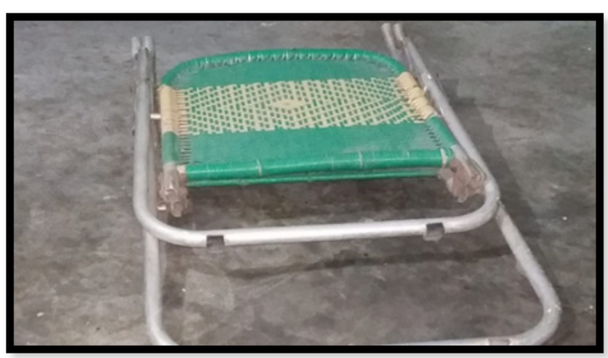

Fig. 4. Plastic chairs

Fig. 5. Plastic tubs

required to reduce plastic pollution in and around the world. Plastic waste degradation by microbes is ecofriendly approach and it won't create any harm to the nature. Recycling and reduction of plastic waste can reduce pollution. Creating mass awareness in the society can attain sustainability. Plastic pollution is ever lasting so to curb plastic pollution people should take individual responsibility and use ecofriendly products.

Conflicts of interest

Author declares no conflicts of interest

ACKNOWLEDGEMENT

I would like to thank management of VFSTR (Deemed to be University) for their encouragement.

REFERENCES

Abe, M., Kobayashi, K., Honma, N. and Nakasaki, K. 2010. Microbial degradation of poly (butylene succinate) by *Fusarium solani* in soil environments. *Polymer Degradation and Stability*. 95(2) : 138-143.https://doi.org/10.1016/j.polymdegradstab.2009.11.042.

Aguado, J., Serrano, D. P. and San Miguel, G. 2007. European trends in the feedstock recycling of plastic wastes. *Global Nest J*. **9**(1) : 12-19.

Barnes, D. K., Galgani, F., Thompson, R. C. and Barlaz, M. 2009. Accumulation and fragmentation of plastic debris in global environments .*Philosophical Transactions of the Royal Society B: Biological Sciences*. 364(1526) : 1985-1998.doi: 10.1098/rstb.2008.0205.

Benedict, C.V., Cameron, J.A. and Huang, S.J. 1983b. Polycaprolactone degradation by mixed and pure cultures of bacteria and a yeast. *J Appl. Polym. Sci*. 28 : 335-342.

Boerger, C.M., Lattin, G.L., Moore, S.L. and Moore, C.J. 2010. Plastic ingestion by planktivorous fishes in the North Pacific Central Gyre. *Marine Pollution Bulletin*. 60 : 2275-2278.

Calabia, B. P. and Tokiwa, 2004. Microbial degradation of poly (D-3-hydroxybutyrate) by a new thermophilic Streptomyces isolate. *Biotechnology Letters*. 26(1): 15-19.

Chatterjee, S., Roy, B., Roy, D. and Banerjee, R. 2010. Enzyme-mediated biodegradation of heat treated commercial polyethylene by *Staphylococcal* species. *Polymer Degradation and Stability*. 95(2): 195-200.

DOI: http://dx.doi.org/10.1016/j.polymdegradstab.2009.11.025.

Crabbe, J. R., Campbell, J. R., Thompson, L., Walz, S. L. and Schultz, W. W. 1994. Biodegradation of a colloidal ester-based polyurethane by soil fungi. *International Biodeterioration & Biodegradation*. 33(2) : 103-113.

Cristina Peda., Letteria Caccamo., Maria Cristina Fossi., Francesco Gai., Franco Andaloro, Lucrezia Genovese., Anna Perdichizzi., Teresa Romeo and Giulia Maricchiolo. 2016. Intestinal alterations in European sea bass *Dicentrarchuslabrax* (Linnaeus, 1758) exposed to microplastics: Preliminary results. *Environmental Pollution*. 212 : 251-256. DOI.org/10.1016/j.envpol.2016.01.083, 2016.

Danko, A. S., Luo, M., Bagwell, C. E., Brigmon, R. L. and Freedman, D. L. 2004. Involvement of linear plasmids in aerobic biodegradation of vinyl chloride. *Applied and Environmental Microbiology*. 70(10) : 6092-6097.

Darby, R. T. and Kaplan, A. M. 1968. Fungal susceptibility of polyurethanes. *Applied Microbiology*. 16(6) : 900-905.

Derraik, J.G.B. 2002.The pollution of the marine environment by plastic debris: a review. *Marine Pollution Bulletin.* 44 : 842-852

De Vargas Mores, Giana, 2018. Sustainability and innovation in the Brazilian supply chain of green plastic. *Journal of Cleaner Production.* 177 : 12-18.

El-Shafei, H.A., Naida, H., El Nasser, A., Kanosh, A. L. and Ali, A.M. 1998. Biodegradation of disposal polyethylene by fungi and Streptomycetes species. *Polym Degrad Stab*. 62 : 361-365.

Fields, R. D., Rodriguez, F. and Finn, R. K. 1974. Microbial degradation of polyesters: polycaprolactone degraded by P. pullulans. *Journal of Applied Polymer Science.* 18(12) : 3571-3579.https://doi.org/10.1002/app.1974.070181207.

Fontanella, S., Bonhomme, S., Koutny, M., Husarova, L., Brusson, J.M., Courdavault, J.P., Pitteri, S., Samuel, G., Pichon, G., Lemaire, J. and Delort, A. 2010. Comparison of the biodegradability of various polyethylene films containing pro-oxidant additives. Polymer *Degradation and Stability*. 95 (6) : 1011-1021.

Gilmore, D.F., Fuller, R.C. and Lenz, R. 2018.

Biodegradation of Poly (Betahydroxyalkanoates). In: Degradable Materials. Florida, CRC Press, USA, 481-514

Gray, J., Evans, N., Taylor, B., Rizzo, J.J. and Walker, M. 2009. State of the evidence: The connection between Breast Cancer and the Environment. *Int J Occu Environ Health*. 15 (1) : 43-78.

Gregory, M.R. 2009. Environmental implications of plastic debris in marine settings – entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. *Philosophical Transactions of the Royal Society B:Biological Sciences*. 364(1526) : 2013-2025. doi:10.1098/rstb.2008.0265.

Gu, J.D. 2003. Microbiological deterioration and degradation of synthetic polymeric materials. *Recent Res. Adv. Int. Biodeterior. Biodegrad*. 52(2) : 69-91.doi:10.1016/S0964-8305(02)00177-4.

Hadad, D., Geresh, S. and Sivan, A. 2005. Biodegradation of polyethylene by the termophilic bacterium *Brevibacillus borstelensis*. *J Appl Microbiol*. 98(5) : 1093-1100. doi:10.1111/j.1365-2672.2005.02553.x.

Hartley, B. L., Pahl, S., Veiga, J., Vlachogianni, T., Vasconcelos, L., Maes, T. and Thompson, R. C. 2018. Exploring public views on marine litter in Europe: perceived causes, consequences and pathways to change. *Marine Pollution Bulletin*. 133: 945-955.

Indumathi, A., Gayathri, T., Biotechnology, E. and Nadu, T. 2016. Plastic Degrading ability of *Aspergillus oryzae* isolated from the garbage dumping sites of Thanjavur, India. *Int. J. Curr. Microbiol. Appl. Sci*. 8(13) : 2319-7706.

Nerland, I. L., Halsband, C., Allan, I. and Thomas, K. V. 2014. Microplastics in marine environments: Occurrence, distribution and effects. 5-11-2014, Research report number.6754-2014; Norwegian Institute for Water Research,Norway.

Iwata, Tadahisa. 2015. Biodegradable and biobased polymers: future prospects of ecofriendly plastics. *Angewandte ChemieInternational, Edition.* 54 (11) : 3210-3215. https://doi.org/10.1002/anie.201410770.

Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A. and Law, K. L. 2015. Plastic waste inputs from land into the ocean. *Science.* 347(6223) : 768-771.

Jansen, B., Schumacher-Perdreau, F., Peters, G. and Pulverer, G. 1991. Evidence for degradation of synthetic polyurethanes by *Staphylococcus epidermidis*. *Zentralblattfür Bakteriologie*. 276(1) : 36-45.https://doi.org/10.1016/S0934-8840(11)80216-1.

Karlsson, S., Ljungquist, O. and Albertsson, A.C. 1988. Biodegradation of polyethylene and the influence of surfactants. *Polymer Degradation and Stability*. 21(3) : 237-250.https://doi.org/10.1016/0141-3910(88)90030-4.

Kay, M.J., Morton, L.H.G. and Prince, E.L. 1991. Bacterial degradation of polyester polyurethane. *Int Biodeterior*. 27(2) : 205-222.https://doi.org/10.1016/0265-3036(91)90012-G.

Khan, S., Nadir, S., Shah, Z. U., Shah, A. A., Karunarathna, S. C., Xu, J., Khan, A., Munir 618 S and Hasan, F. 2017. Biodegradation of polyester polyurethane by *Aspergillus* 619 tubingensis. *Environmental Pollution*. 225 : 469-480. DOI: 620 https://doi.org/10.1016/j.envpol.2017.03.012.

Kleeberg, I., Hetz, C., Kroppenstedt, R. M., Müller, R. J. and Deckwer, W. D. 1998. Biodegradation of aliphatic-aromatic copolyesters by *Thermomono sporafusca* and other thermophilic compost isolates. *Applied and Environmental Microbiology*. 64(5) : 1731-1735.

Kumar, R., Vimal, G. R., Kanna, and Elumalai, S. 2017. Biodegradation of polyethylene by green photosynthetic microalgae. *J Bioremediat Biodegrad.* 8.381 : 2.

Koutny, M., Amato, P., Muchova, M., Ruzicka, J. and Delort, A. M. 2009. Soil bacterial strains able to grow on the surface of oxidized polyethylene film containing prooxidantadditives. *International Biodeterioration and Biodegradation.* 63 (3) : 354-357. doi: http://dx.doi.org/10.1016/j.ibiod.2008.11.003.

Laist, D. W. 1987. Overview of the biological effects of lost and discarded plastic debris in the marine environment. *Marine Pollution Bulletin*. 18(6) : 319-326.

Lee, B., Pometto, A.L., Fratzke, A. and Bailey Jr., T.B. 1991. Biodegradation of degradable plastic polyethylene by Phanerochaete and *Streptomyces* species. *Appl. Environ. Microbiol*. 57(3) : 678-685.

Liu, E. K., W. Q. He, and Yan, C. R. 2014. White revolution'to 'white pollution –agricultural plastic film mulch in China. *Environmental Research Letters*. 9(9) : 091001.

Lilac, W. D. and Lee, S. 2001. Kinetics and mechanisms of styrene monomer recovery from waste polystyrene by supercritical water partial oxidation. *Advances in Environmental Research*. 6(1) : 9-16.

Maa, S., Daphi, D., Lehmann, A. and Rillig, M. C. 2017. Transport of microplastics by two collembolan species. *Environmental Pollution*. 225 : 456-459.https://doi.org/10.1016/j.envpol.2017.03.009.

Maffini, M. V., Rubin, B. S., Sonnenschein, C. and Soto, A. M. 2006. Endocrine disruptors and reproductive health: the case of bisphenol-A. *Mol. Cell. Endocrinol.* 254 : 179-186.https://doi.org/10.1016/j.mce.2006.04.033.

Mee, A., Rideout, B. A., Hamber, J. A., Todd, J. N., Austin, G., Clark, M. and Wallace, M. P. 2007. Junk ingestion and nestling mortality in a reintroduced population of California Condors

Gymnogypscalifornianus. *Bird Conserv. Int*. 17(2) : 119-130.DOI: https://doi.org/10.1017/S095927090700069X.

Mogil'nitskii, G. M., Sagatelyan, R. T., Kutishcheva, T. N., Zhukova, S. V., Kerimov, S. I. and Parfenova, T. B. 1987. Disruption of the protective properties of the polyvinyl chloride coating under the effect of microorganisms. *Prot. Met.(Engl. Transl.);(United States)*. 23 (1) : 173-175.

Moore, C. J. 2008. Synthetic polymers in the marine environment: a rapidly increasing, long-term threat. *Environmental Research*. 108(2) : 131-139.https://doi.org/10.1016/j.envres.2008.07.025

Mor, R. and Sivan, A. 2008. Biofilm formation and partial biodegradation of polystyrene by the actinomycete Rhodococcusruber. *Biodegradation*. 19(6) : 851-858. DOI 10.1007/s10532-008-9188-0.

Nizzetto, L., Futter, M. and Langaas, S. 2016. Are agricultural soils dumps for microplastics of urban origin?10777-10779.https://doi.org/10.1021/acs.est.6b04140.

Norman, R.S., Frontera-Suau, R. and Morris, P.J. 2002. Variability in *Pseudomonas aeruginosa* lipopolysaccharide expression during crude oil degradation. *Appl Environ Microbiol*. 68(10) : 5096-5103. https://doi.org/10.1128/AEM.68.10.5096-5103.2002

Nowak, B., Pajak, J., Drozd-Bratkowicz, K.M. and Rymarz, G. 2011. Microorganisms participating in the biodegradation of modified polyethylene films in different soils under laboratory conditions. *International Biodeterioration & Biodegradation*. 65 (6) : 757-767. DOI: http://dx.doi.org/10.1016/j.ibiod.2011.04.007.

Orr, I.G., Hadar, Y. and Sivan, A. 2004. Colonization, biofilm formation and biodegradation of polyethylene by a strain of Rhodococcusruber. *Applied Microbiology and Biotechnology*. 65(1) : 97-104.

Pathirana, R. A. and Seal, K. J. 1985. Studies on polyurethane deteriorating fungi. *Int. Biodeterior. Biodegrad*. 21 : 41-49.

Paco, A., Duarte, K., Costa, J., Santos, P., Pereir,a R., Pereira, M.E., Freitas A., Duarte 690 A. and Rocha-Santos, T. 2017. Biodegradation of Polyethylene Microplastics By The 691 Marine Fungus Zalerion Maritimum. *Science of The Total Environment*. 586: 10-15. DOI: https://doi.org/10.1016/j.scitotenv.2017.02.017

Peda, C., Caccamo, L., Fossi, M. C., Gai, F., Andaloro, F., Genovese, L. and Maricchiolo, G. 2016. Intestinal alterations in European sea bass *Dicentrarchus labrax* (Linnaeus, 1758) exposed to microplastics: preliminary results. *Environmental Pollution*. 212 : 251-256.

Pilz, H., Brandt, B. and Fehringer, R. 2010. The impact of plastics on life cycle energy consumption and greenhouse gas emissions in Europe. Summary report June; denkstatt GmbH, Vienna, Austria.

Pometto, A. L., Lee, B. T. and Johnson, K. E. 1992. Production of an extracellular polyethylene-degrading enzyme (s) by *Streptomyces* species. *Applied and Environmental Microbiology*. 58(2) : 731-733.

Raaman, N., Rajitha, N., Jayshree, A. and Jegadeesh, R. 2012. Biodegradation of plastic by *Aspergillus* spp. isolated from polythene polluted sites around Chennai. *J Acad Indus Res*. 1(6) : 313-316.

Rajandas, H., Parimannan, S., Sathasivam, K., Ravichandran, M. and Yin, L. S. 2012. A novel FTIR-ATR spectroscopy based technique for the estimation of low-density polyethylene biodegradation. *Polymer Testing*. 31(8) : 1094-1099.https://doi.org/10.1016/j.polymertesting.2012.07.015.

Raziyafathima, M., Praseetha, P.K., Rimal Isaac, R.S. 2016. Microbial degradation of plastic waste: a review. *J Pharma Chem Biol Sci*. 4 : 231-242) add (Singh B, Sharma N (2008) Mechanistic implications of plastic degradation. *Polym Degrad Stab*. 93(3) : 561 584. https://doi.org/10.1016/j.polymdegradstab.2007.11.008)

Rathi, S. 2006. Alternative approaches for better municipal solid waste management in Mumbai. *India. Journal of Waste Management*. 26 : 1192-1200.https://doi.org/10.1016/j.wasman.2005.09.006.

Rochman, C. M., Kross, S. M., Armstrong, J. B., Bogan, M. T., Darling, E. S., Green, S. J and Veríssimo, D. 2015. Scientific evidence supports a ban on microbeads. *Environ. Sci. Technol*. 2015, 49(18): 10759-10761.https://doi.org/10.1021/acs.est.5b03909.

Roy, P.K., Titus, S., Surekha, P., Tulsi, E., Deshmukh, C. and Rajagopal, C. 2008. Degradation of abiotically aged LDPE films containing pro-oxidant by bacterial consortium. *Polymer Degradationand Stability*. 93(10) : 1917-1922.

DOI: http://dx.doi.org/ 10.1016/j.polymdegradstab.2008.07.016.

Roy, P. K., Hakkarainen, M., Varma, I. K. and Albertsson, A. C. 2011. Degradable polyethylene: fantasy or reality. *Environmental Science & Technology*. 45(10) : 4217-4227.https://doi.org/10.1021/es104042f.

Rudel, R. A., Attfield, K. R., Schifano, J. N. and Brody, J. G. 2007. Chemicals causing Mammary Gland Tumors in animals Signal new directions for Epidemiology, chemicals testing, and risk assessment for breast cancer prevention. *Cancer: Interdisciplinary International Journal of the American Cancer Society*. 109 : 2635-2666. https://doi.org/10.1002/cncr.22653.

Ryan, P. G., Connell, A. D. and Gardner, B. D. 1988.

Plastic ingestion and PCBs in seabirds: is there a relationship? *Marine Pollution Bulletin*. 19(4) : 174-176.

Raziyafathima, M., Praseetha, P.K. and Rimal Isaac, R.S. 2016. Microbialdegradation of plastic waste: a review. *J Pharma Chem Biol Sci*. 4 : 231-242.

Sharma, S. and Chatterjee, S. 2017. Microplastic pollution, a threat to marine ecosystem and human health: a short review. *Environmental Science and Pollution Research*. 24 (27) : 21530-21547. DOI 10.1007/s11356-017-9910-8, 2017

Sivan, A., Szanto, M. and Pavlov, V. 2006. Biofilm development of the polyethylene-degrading bacterium *Rhodococcus ruber*. *Appl Microbiol Biotechnol*. 72(2) : 346-352

Sivasankari, S. and Vinotha, T. 2014. In Vitro Degradation of Plastics (Plastic Cup) Using *Micrococcus luteus* and *Masoniella* Sp, Sch. *Acad J Biosci*. 2(2) : 85-89

Singh, B. and Sharma, N. 2008. Mechanistic implications of plastic degradation. *Polym Degrad Stab*. 93(3) : 561-584. https://doi.org/10.1016/j.polymdegradstab.2007.11.008

Stoleru, E., Hitruc, E. G., Vasile, C. and Oprica, L. 2017. Biodegradation of poly (lactic acid)/chitosan stratified composites in presence of the Phanerochaetechrysosporium fungus. *Polymer Degradation and Stability*. 143 : 118-129. DOI: https://doi.org/10.1016/j.polymdegradstab.2017.06.023.

Tezuka, Y., Ishii, N., Kasuya, K. I. and Mitomo, H. 2004. Degradation of poly (ethylene succinate) by mesophilic bacteria. *Polym Degrad Stab*. 84(1) : 115-121. https://doi.org/10.1016/j.polymdegradstab.2003.09.018

Tokiwa, Y., Ando, T. and Suzuki, T. 1976. Degradation of polycaprolactone by a fungus. *J FermTechnol*, 54(8) : 603-608.

Tokiwa, Y., Calabia, BP., Ugwu, CU. and Aiba, S. 2009. Biodegradability of plastics. *Int J Mol Sci*. 10 (9) : 3722-3742. doi: 10.3390/ ijms10093722.

Uemichi, Y., Hattori, M., Itoh, T., Nakamura, J. and Sugioka, M. 1998. Deactivation behaviors of Zeolite and Silica- Alumina catalysts in the degradation of polyethylene. *Ind. Eng. Chem. Res.* 37 : 867-872. doi: 10.1021/ie970605c

Walther, B. 2015. Nation engulfed by plastic tsunami. Taipei Times. http://www. taipeitimes.com/News/editorials/archives/2015/01/09/2003608789/2.

Watanabe, T., Ohtake Y., Asabe, H., Murakami, N. and Furukawa, M. 2009. Biodegradability and degrading microbes of low-density polyethylene. *Journal of Applied Polymer Science*. 111(1) : 551-559. https://doi.org/10.1002/app.29102.

Webb, H. K., Arnott, J., Crawford, R. J. and Ivanova, E. P. 2013. Plastic degradation and its environmental implications with special reference to poly (ethylene terephthalate). *Polymers*. 5(1) : 1-18. doi: 10.3390/polym5010001.

Xanthos, D. and Walker, T.R. 2017. International policies to reduce plastic marine pollution from single-use plastics (plastic bags and microbeads): a review. *Marine Pollution Bulletin*. 118 (1-2) : 17-26. http://dx.doi.org/10.1016/j.marpolbul.2017.02.048.

Yamada-Onodera, K., Mukumoto, H., Katsuyaya, Y, Saiganji, A. and Tani, Y. 2001. Degradation of polyethylene by a fungus *Penicillium simplicissimum* YK. *Polym Degrad Stab*. 72 (2) : 323-327.https://doi.org/10.1016/S0141-3910(01)00027-1.

Yoshida, S., Hiraga, K., Takehana, T., Taniguchi, I., Yamaji, H., Maeda, Y., Toyohara, K., Miyamoto, K., Kimura, Y. and Oda, K. 2016. A bacterium that degrades and assimilates poly (ethylene terephthalate). *Sci.* 351(6278) : 1196-1199. https://doi.org/10.1126/science.aad6359

Zhu, Z. and Zuo, Y. 2013. Bisphenol A and other alkylphenols in the environment-occurrence, fate, health effects and analytical techniques. *Advances in Environmental Research*. 2(3): 179-202. https://doi.org/10.12989/aer.2013.2.3.179.