POTENTIAL OF FUNGI FOR BIODEGRADATION OF PLASTICS

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This review describes the role of Fungi to degrade different sort of plastics by various strategies like using extracellular enzymes having capacity to degrade nonspecific substrates. Hydrophobins, unique proteins produced by fungi for surface coating to attach hydrophobic surfaces renders fungal penetration is also covered in it. Fungal studies on various forms of plastic biodegradation have shown that fungi can use these substances as their sole source of carbon and leads to complete degradation in some cases (Lucas *et al.* 2008, Singh and Sharma 2008, Kolvenbach *et al.* 2014). Further research is needed to develop new isolates in the plastic sphere ecosystem, to use molecular methods to degrade plastics to increase enzyme activity levels, and to use omic-based techniques to accelerate biodegradation of plastic wastes. Consideration should also be given to reducing the amount of biocides and antioxidant stabilizers used in the plastic manufacturing process, as well as the types of oxidizers (photosensitizers) used to promote biodegradation. Interdisciplinary research and innovative fungal strategies for biodegradation of plastic waste are also needed.

With an increasing population and demand of durability plastic's yearly production is surpassed 350-400 million tons (Geyer 2017). Hazardous effects of plastic are known since years (Jambeck *et al.* 2015) and scientists worldwide are trying to come up with new technology to deal with it. Recycling, which is the most common practice to deal with plastic problem is not a viable solution (Alexander 2019) as these materials continue to accumulate in the environment in form of Macro- Meso, micro- and nano-plastics (Blettler *et al.* 2017). Other solutions like development and production of Biodegradable plastic is also referred as potential remedy to worldwide quandary, but it has its own setbacks (Haider *et al.* 2019).

Biodegradation, *i. e.* degradation of organic chemicals into simple compounds by living organism such as Microbes and fungi is one of the effective and emerging solutions to plastic problem. Multiple efforts are being carried out to find and isolate microorganism capable of utilizing synthetic polymers as their carbon source for growth (Khan *et al*. 2000).

These materials may have significant synthetic and physical effects on the condition and human wellbeing on account of their exceptional physiochemical miniaturized scale and nanoscale properties (Mattsson *et al.* 2015, Waring *et al.* 2018, Peiponen *et al.* 2019). Because of these worries, there is a need to look for options for tidying up the condition. Bioremediation is viewed as the most attractive methodology for dispensing with numerous natural poisons. Bioremediation is an ecologically neighborly and minimal effort innovation which can be embraced nearby since it includes regular procedures (Das and Adholeya 2012). In this sense, Fungi have promising handy applications to remediate conditions ruined by plastics utilizing their enzymes.

What are Macro and Micro Plastics?

Plastics are generally classified according to their structural properties, applications and physical properties. They can be homopolymers or heteropolymers if they are made up of identical or different monomers respectively. Similarly they are also divided on the basis of their chemical structure of backbone and side chains into thermoplastics and thermosets. Thermoplastics have uncrossed linking and are recyclable but thermosets also known as Duroplastics have high density cross linking and are non recyclable (Eyerer and Elsner 1998). Plastics made up with particles with a diameter b 5mm, are called Microplastics according to NOAA (National Oceanic and Atmospheric Administration), while those with b1 μm are called as nano-plastics (GESAMP 2015, NOAA 2015). Microplastics can be further divided into i) Primary Microplastics which are produced at microplastic size such as vector for medicine (Williams 1981) or Plastic-based granules in cosmetic industry (Anderson *et. al.* 2016) and ii) Secondary Microplastics, which are produced by fragmentation of Macro-plastics and Meso-plastics such as Glass bottles and Plastic bags (Cole *et al.* 2011, Rocha-Santos and Duarte 2015).

There are several ways of Plastic degradation. Commonly used ones are Mechanical or chemical methods. This breakage can be brought about by mixture of chemicals and physical maturing, just as through biodegradation process. The latter is the efficient environment friendly procedure in the advancement of large scale plastics to small scale plastics in the sea (Lambert *et al.* 2014, Sivan 2011). As of late, there have been various reports itemizing the remarkable increment in the measure of these particles in the seas, with iniquitous results to nature and biota (Browne *et al.* 2008, Cole *et. al.* 2013, Ivar do Sul and Costa 2014), including economically important species (Avio *et al.* 2015, Neves *et al.* 2015).

When in nature, (small scale) plastics are dependent upon biotic as well as abiotic components for degradation. Biotic, or biodegradation is mediated by microorganisms and henceforth is characterized as a "procedure which is equipped for decay of materials into carbon dioxide, methane, water, inorganic mixes, or biomass in which the prevalent component is the enzymatic activity of microorganisms, that can be estimated by standard tests, in a predefined timeframe, reflecting accessible removal conditions" (ASTM 2010). Biodegradation is affected by both the qualities of the polymer, including concoction and physical properties, and natural components, for example, light (UV), humidity, heat and the presence of chemicals (Shah *et al.* 2008).

As of late, bioremediation of plastic waste was considered as a monetary and environment safe methodology for plastic waste administration that could thoroughly diminish the extreme contamination delivered from the traditional plastic remediation techniques (Muenmee *et al.* 2016, Broszeit *et al.* 2016). The two growths and microscopic organisms have exhibited their capacity for plastic degradation by certain investigations which demonstrated consortium of microbial species in the degradation of both normal and engineered plastics (Gu *et. al.* 2000, Tokiwa *et al.* 2009, Zafar *et al.* 2014, Lipsa *et al.* 2016). Be that as it may, organisms could assume an amazing work in degradation of polymers in soil because of their high capacity to produce assorted enzymes, for example, Glucosidase, Cutinase, amylase, lipase, esterase, cellulase, pectinase and hemicellulase (Kim and Rhee 2003, Maeda and Yamagata 2005, Anastasi *et al.* 2013). A couple of past research have segregated Fungi from plastic polluted soils and researched its capacity in degrading plastic polymers (Zahra *et al.* 2010, Raaman *et al.* 2012, Sumathi *et al.* 2016, Indumathi and Gayathri 2016). Zahra *et al.* (2010) found that the Fungi confines that were recovered from plastic polluted landfill and were identified as *Acremonium flavum*, *Candida rugosa*, *Arthrographis kalrae*, *Aspergillus sp*., *Lichtheimia sp*., *Aspergillus fumigatus*, *Emericella nidulans*, *Aspergillus terreus* and *Fusarium solanifrom* had a high efficiency in colonizing and degrading polyethylene. Additionally, Raaman *et al.* (2012) researched the decent variety of organisms in plastic polluted soils and their capacity of polyethylene degradation under lab conditions. As of late, many examinations shed the light on the identification and characterization of fungal strains from polluted soils. One investigation confined fungal strains from open dump site tainted with plastic and screened them for laccase secretion, which is a basic protein for biodegradation of polymers (Sumathi *et al.* 2016). Then again, Indumathi and Gayathri (2016) identified fungal strains from plastic polluted soil and researched their efficiency in plastic degradation in situ.

Plastic trash in the earth represents a noteworthy risk particularly due to its resistivity to photo-oxidative, heat, mechanical and natural procedures of degradation (Shah *et al.* 2008, Zbyszewski *et al.* 2014). Even though neglected for a long time, the measure of plastic trash collecting in the earth has been consistently expanding because of the material's toughness and lightweight nature (Thompson *et al.* 2009, Goldstein *et al.* 2012). Once disposed off, plastic goes and accumulates in water bodies that operate as sinks for low-density litter (Moore 2008, Ericksen *et. al.* 2014, Jambeck *et al*. 2015). Geography, wind and water flows, and propinquity to contamination sources control the quantity and types of plastics along shorelines, while degradation process decide to what extent plastic wreckage stays on sea shores (Derraik 2002, Barnes 2009).

Why biodegradable plastic is not an alternate?

The aggregation of plastic items has prompted expanding the measures of plastic contamination around the globe. Plastic squanders are regularly accumulated in soil because of the exceptionally slow degradation. As a result, the harmful synthetic molecules within the plastic structure (for example bis-phenol A and phthalates) are discharged in the soil and influence adversely both soil biological system and human wellbeing (Shah *et al.* 2008, Das and Kumar 2014).

Potential hazards of Biodegradable plastics: Plastic characterized as "biodegradable" is made of atoms that can separate normally, however there is no specific timescale determined for this degradation - under certain conditions it can take numerous years. Some biodegradable plastic is likewise said to be "compostable", and for this situation it must hold fast to stricter conditions. One example is polylactide (PLA), which is utilized to make food package.

A modern commercial plastic degradation unit supplies the fundamental uniformity of heat, dampness, air and microorganisms to effectively compost food and other compostable waste. In any case, with a requirement for temperatures of 600C or more, these are not conditions that can be given by being covered in the ground or in a manure store at home. The compostable plastic pack broke down in presence of air and water in the ocean, however was as yet present covered in soil after over two years. These plastics are commonly not intended to degrade without exceptional treatment, which are not possible at normal atmospheric conditions. So, when spilled into the earth as litter – as exhibited by the Plymouth study -they can be as unsafe as ordinary plastics got from non-renewable energy sources. There is no worldwide standard for home compostable plastics (Song *et al.* 2009).

The rise of bioplastics: The other kind of degradable plastic is produced using oxo-biodegradable material. These are regular plastics, yet they contain added substances which, after a suitable time delay, permit the plastic to respond with oxygen which splits it down – accelerating the degradation responses that would some way or another happen more than several years. Yet, these plastics are additionally fairly questionable, as proof proposes that they don't biodegrade totally as their manufacturer's guarantee, however rather separate into micro-plastics which may continue in the earth.

The Ascent of Bioplastics: The universal idea of plastics overall should be change to making them from natural sources on the off chance that we are to end our reliance on non-renewable energy sources. There are evidences that creating plastics from plants has a smaller negative ecological effect than making them from raw petroleum (Da Luz *et al.* 2013). However, as has been seen with biofuels, this sets new issues through utilization of land that could somehow be developing food crops. This is probably going to improve as there is lot of research going on to improve bioplastics mechanical procedures and progressively proficient innovation. Feed stocks, for example, food squander, could likewise be utilized.

Be that as it may, bioplastics should likewise be discarded effectively similarly as with traditional plastics, and the presence of compostable plastics must not turn into a reason to litter. Rather, compostable plastics can be joined into a round commercial model, where waste is recuperated and changed over into valuable items, or where compostable plastics and food squander and be come back to the soil as supplements.

While progressively manageable plastic options exist, they can't be a supportable alternate without the foundation required to fabricate, gather and reuse them at large scale. Right now, the various sorts of biodegradable and traditional plastic being used can present issues for built up reusing frameworks in the event that they are blended.

According to Central pollution control Board, In year 2017-18 plastic waste generated in India was 660,787.85 tonnes and only 60% of the total plastic waste is being recycled (Banerjee 2009) and compostable or biodegradable plastics that are unsupported by existing reusing frameworks go to landfill or incineration. At present, around 33% of plastic bundling overall winds up in the earth – thus without huge changes, there will be more plastic by weight than fish in the seas by 2050.

Role of Fungi as potential agent for Biodegradation: Fungi establish a huge and different realm of eukaryotic life forms morphologically diverse yeasts, filamentous parasites, or dimorphic growths. These creatures can be saprotrophs such as deteriorating dead material or committed or shrewd life forms such as decomposers, mutualists or pathogens (Schmit and Mueller 2007, Črešnar and Petrič 2011). Fungi are found in various conditions and some of them have advanced to adjust furthermore, become even in terrestrial and marine environment under extraordinary conditions (Raghukumar 2017). Mostly grow in aerobic conditions, however anaerobic fungi have been found in freshwater lakes, landfill destinations, and the rumen of herbivores (Ivarsson *et al.* 2016). Fungi have the ability to stretch out through substrates as they continued looking for nutriments with their filamentous system structure, searching and developing in places that are progressively difficult for other microorganisms (Figure 1).

Filamentous Fungi are the most usually classified species of fungi to date. These creatures have built up an extraordinary capacity to adjust to changing environment and to endure a few kinds of pollutants. They can separate and utilize these pollutants to develop or to make their compound segments accessible to different microorganisms for further degradation. As a result, filamentous growths assume an essential job in the degradation and mineralization of differing ecological pollutants by catalyzing significant chemical reactions (Črešnar and Petrič 2011). As fungi are heterotrophic life forms they discharge digestive proteins by exocytosis outside of their hyphae, which separate large scale and natural atoms into small natural compound to assimilate them back, liberating CO2 and H2O under vigorous conditions (and CH4 under anaerobic conditions) if mineralization of the substrate happens (Pathak and Navneet 2017) (Fig. 2). Fungi have different phenomenal techniques to neutralize various complex pollutants; some of them are toxic and poisonous substances (Olicón-Hernández *et al.* 2017). These systems incorporate an amazing enzymatic framework, the capacity of adsorption and the creation of characteristic biosurfactants (i.e., hydrophobins), which empower them to utilize polymers (*i.e.* plastics) as a wellspring of carbon and electrons, furnishing them with cell materials and a vitality source, individually.

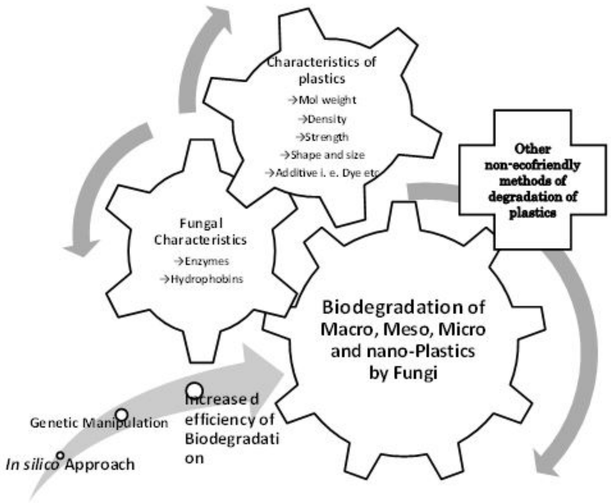

Figure 1: Biodegradation Framework of plastics by Fungi

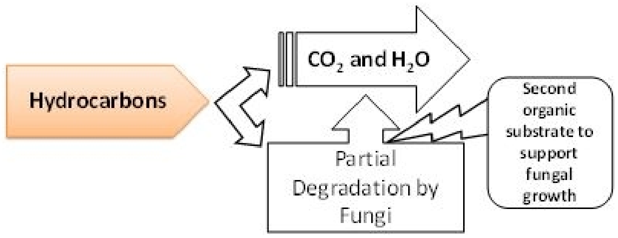

Figure 2: outline of Biodegradation process by Fungi

Degradation proces

(I) Enzymes involved in degradation pathway: The development of the microorganisms responsible for biodegradation must be streamlined by controlling the moisture, temperature, incubation time and the substrate like polyethylene, polyurethane which are devoured as a carbon and vitality source. This helps in the creation of enormous measure of catalyst. These microbial proteins incite the pace of biodegradation of plastics successfully without making any harm to the earth.

There are many reports and discoveries accessible that recommend that the biodegradation of plastic or polyethylene happens with the assistance of enzymes (Raaman 2015). The reports envelop the possibility of the two microbes and growths in this specific viewpoint. A few life forms, including microorganisms *Pseudomonas chlororaphis* and *Comomonas acidovorans* just as the growth *Candida rugosa* are the wellspring of proteins and chemicals like putative polyurethanases which have been separated and portrayed. The dynamic enzymes have been assembled as esterases, lipases, proteases and ureases which degrade the polyurethane substrate by severing the ester bonds. *Pestalotiopsis microspora*, the endophytic organisms has been detached containing serine hydrolase use the polyurethane as a carbon source and degrades it within the time period of couple of days (Russell 2011).

The microbial enzymes, for example, depolymerase, esterase and lignolytic ones, that cut the polymers into little chains, might be associated with the plastics degradation (Shah 2008, Da Luz 2013, Gu 2003, Sato 2017). In this manner, white rot fungi have an extraordinary potential, since they are chemicals makers and have demonstrated their capacity for treatment of industrial waste (Purnomo 2010, Nunes 2014, Oleveira 2018). An ongoing examination article has proposed that the presence of chemical groups, for example, esterases, lipases and cutinases are generally accountable for degrading various types of plastic(Hadad *et al.* 2005). A tale enzyme was likewise recognized as ISF6_4381 secreted by the novel strain *Ideonella sakaiensis* 201-F6 was seen as responsible for the degradation of PET (Polyethylene terephthalate) (Sivan 2006). Microorganisms, specially microbes for instance *Brevibacillus borstelensis* (Gilan 2004) , *Rhodococcus elastic* (Yamada *et al.* 2001, Bharathidasan and Prince 2016) and Fungi (heterotrophic microorganisms, for example, *Penicillium simplicissimum* YK (Howard *et al.* 2002, Glass JE and Swift 1989), *Fusarium solani* (Gu *et al*. 2001) are accounted for to be utilized in degradation of both characteristic and engineered polyethylene as its potential carbon substrate(Devi *et. al.* 2016, Shah *et. al.* 2015, Dineshraj D. and P. Ganesh 2016). Human activities ought to be focused on creating eco-accommodating techniques for degradation of manufactured plastics by using the capability of microorganisms in decomposing different types of plastics (El-Shafei *et al.* 1998, Anderson *et al.* 2003, Deepika *et al.* 2015).

(ii) *In-silico* approach: The principle polymers that are delivered and of significance to our economy are polyurethane (PUR), polyethylene (PE), polyamide (PA), polyethylene terephthalate (PET), polystyrene (PS), polyvinylchloride (PVC), and polypropylene (PP). Fungal cutinases demonstrated action on PET substrates also. The most noticeable examples are cutinases of the phyla Fusarium and Humicola. The last was additionally utilized together with the lipase CalB from *Candida antarctica* so as to go around the recently referenced item hindrance by BHET and MHET (Carniel *et al.* 2017). While CalB totally changed over to terephthalic corrosive, the Humicola-determined enzyme was restricted in thxzu11234567890-e last response step and collected the moderate MHET. Utilizing an in silico genome mining approach, a cutinase from *Pseudomonas pseudoalcaligenes* (PpCutA) and a putative lipase from *Pseudomonas pelagia* (PpelaLip) were distinguished as potential chemicals following up on polyesters when all is said in done. Further exploratory work utilizing recombinant enzymes of PpCutA and PpelaLip confirmed the hydrolytic action of the two proteins on various kinds of polyesters, including the hydrolysis of polyoxyethylene terephthalate (Haernvall *et al.* 2017). In their investigation, the creators utilized fundamentally unique ionic phthalic corrosive based polyesters with a normal sub-atomic weight running from 1,770 to 10,000 g/mol and semi-crystalline polyesters with crystallinity beneath 1% to test and check the microbial debasement. Prominently, the identified organism is related to a biotechnologically significant novel species of the family Pseudomonas, which was assigned as *Pseudomonas pertucinogena* (Bollinger *et. al.* 2018).

(iii) Biodegradation pathways: During the degradation of homopolymeric plastic materials, one sort of monomer is being created, which either experiences beta-oxidation or TCA cycle (Shah *et al.* 2008, Koutny *et al.* 2006). At the point when the polymer is contained at least two monomer, the degradation gets troublesome. In those cases, a solitary species could complete a few phases of degradation, yet not all. By and large, the total degradation pathways qualities are supplemented by designing distinctive engineered bacterial species. Furthermore, an European site has revealed during PET degradation, *E.coli* BL-21 integrates LC-cutinase which hydrolyzes the polymer to yield terephthalate and ethylene glycol as two key monomers, this is the initial phase in the degradation pathway (iGEM 2016). Polymers harboring hydrocarbon chains are degraded by polyurethenase alkane monoxygenase cutinase and amylase usually named as depolymerases (Seneviratne *et al.* 2006). A strain got from *Commamonas testosteroni* degrades terephthalate and ends in a toxic molecule, protocatechuate. Thus, *P. putida* uses protocatechuate and experiences degradative pathway by enlisting different dioxygenases to use it as a supplement source (Jimenez *et al.* 2002).

The ethylene glycol is additionally degraded and mineralized by E.coli BL-21 to CO2 and H2O. In some cases, bacterial strains are genetically engineered and supplemented with different qualities of the pathway to do degradation (Goodman 2008). The polymer can be separated *in vitro* into its comparing monomers, or the engineered strain may have transporters which are combined with the degradation pathway qualities to degrade the molecules inside the cell (Dress 2010). As on account of polyurethane (PUR) degradation, polyurethane esterase separates PUR polymer into ethylene glycol, which can diffuse over the film of the bacterium (Kang *et al*. 2011). Nonetheless, osmY, encodes osmotic inducible protein Y, that wires with PUR esterase and sends out the degraded compound outside the cell (Bokinsky *et al*. 2011, Kang *et al*. 2011). The built strain additionally contains an operon in a subsequent plasmid made out of glycoaldehyde dehydrogenase (*ald*A) and glycolaldehyde reductase that permits the bacterium to utilize ethylene glycol as its central metabolite. Henceforth, there are possibilities where complete degradation catalysts are available in a solitary species (Boronat *et al.* 1983). It permits the species to act naturally adequate in using PUR as a supplement source to change over the plastics into bacterial biomass which would, thus, degrade more PUR. (Dress 2010). iGEM groups have planned a bioreactor where they have utilized genetically engineered *E. coli* to degrade PUR. The construct is outfitted with PUR esterase transport apparatus and secretion tags. With this assembly, PUR esterase will be discharged from the cell. It at that point assaults the polymer and divides the ester bond to discharge ethylene glycol and sugars. Ethylene glycol will be used by a different species and sugars are accordingly devoured to create biomass.

(iv) Hydrophobins: Hydrophobins, low molecular mass ($\leq$20 kDa) discharged proteins of growths, are described by moderate to elevated levels of hydrophobicity and presence of eight cysteine (Cys) amino acid residues. These proteins can gather precipitously into amphipathic monolayers at hydrophobic–hydrophilic interfaces. Though useful homologues are accounted for in Streptomyces (chaplins, SapB, and SapT for elevated morphogenesis; (Kodani 2005*)*), hydrophobins are interesting to the Fungal kingdom. fungal genome examinations have demonstrated that hydrophobins for the most part exist as gene families with two to ten individuals, albeit certain species contain more individuals e.g., *Coprinus cinereus* shows 33 members (Sunde *et al*. 2008, Littlejohna *et al*. 2012).

In view of hydropathy plots, solubility and the sort of layer they construct, hydrophobins are isolated into two classes, albeit ongoing bioinformatics research recommend that middle/various structures can likewise exist and that numerous hydrophobins with particular physicochemical attributes may have been unnoticed in the past (Littlejohna *et al.* 2012, kwan *et al.* 2006, Wessels 1997, Jensen *et al.* 2010) .

The potential uses of hydrophobins depend on their capacity to switch the hydrophilic-hydrophobic character of a surface as well as their surfactant limit. A few biotechnological uses of hydrophobins have been proposed (Linder *et al.* 2005, Mustalahti *et al.* 2011). However, the huge scope uses of hydrophobins may be hard to actualize because of the creation cost of recombinant proteins or potentially the large scale requirements of the proteins.

Characterization of Plastic Biodegradation

As plastics are the polymers which breakdown into little units of monomers or oligomers. A portion of the polymers are water dissolvable (when they get emulsified) so they are degraded into natural intermediates like acids, alcohols also, ketones and so forth. Following are a few focuses which help in the checking of biodegradation of the plastics (Arutchelvi 2008).

1. Properties of the plastic are changed physically and mechanically.
2. Changes in the outside surface of the plastics.
3. Rate of carbon dioxide development by plastic utilization.
4. Chemical analysis of the items.
5. Rate of utilization of oxygen.
6. Biomass accumulation, which shows the use of plastics as the sole carbon source for the development of microorganisms.

Fungal strains reported for Biodegradation of plastics: The plastics polymers degradation is detected by observing mechanical, optical or electrical attributes, erosion, cracking, fission, staining, phase separation and discoloration after degradation process (Shah 2006).

Number of Fungi was isolated from the outside of polyester PU froth, utilizing it as a sole carbon source. These growths segregates were recognized and found to have a place from the genera *Emericella*, *Trichoderma*, *Aspergillus*, *Fusarium*, *Gliocladium* and *Penicillium* (Bentham 1987). *Geomyces pannorum* was seen as the overwhelming growths comprising 22–100 % of the polyester PU debasing organisms (Barratt 2003). Different genera of the growths including most of the life forms found in soil for the degradation of polyurethane like *Plectosphaerella, Nectria, Neonectria, Phoma* and *Alternaria*. The revealed biodegradation movement with Aspergillus niger was seen to be very delayed with noticeable indications of weakening happening simply following 30 days (Russell 2011).

Fungi show explicit physiological and metabolic ad over advantages over bacteria, since they don't depend entirely on soluble, promptly available chemical compounds for nourishment. They secrete a wide variety of enzymes into their surroundings that cut polymeric substances (Harms *et al.* 2011). The solvent breakdown items are at that point ingested and further catabolized by intra cellular enzymes.

Other than the essential fungal oxidizers, numerous different microorganisms get benefit by the released substrates. Complex interactions happen that instigate organisms to co-develop complex processes, going from producing of antibiotics on the negative side, to the particular provocation of indigenous microbes on the positive side (de Boer *et al.* 2005, Kohlmeier *et al.* 2005). Along these lines, in nature, Fungi assume an imperative job in the degradation of many "stubborn" polymeric natural mixes, for example, cellulose, chitin, melanin, lignin and keratin. Because of this biochemical diversity, the biodegradation of a few inadequately biodegradable/bioavailable xenobiotics can be achieved with fungi by co-metabolism (Raj *et al.* 1992). Under such conditions, the parent hydrocarbons can be degraded up to various extents, from partial to complete biodegradation, yet a second natural substrate is frequently needed for fungal growth development.

CONCLUSION

Furthermore, fungi show a particular physiological versatility during growth by their filamentous hyphae, a vegetative mode that provides interior translocation of supplements over a range of substrates, for example, soil particles and wood without the need of a fluid. Therefore, numerous fungi are tolerant towards constrained water and supplement accessibility. They likewise grow well in acidic conditions (Wainwright 1993) that hinder numerous microbes.

Plastics are thermo-elastic; water-insoluble, polymers are representing many extraordinary environmental challenges. Microbial degradation is better than physical and chemical strategies as the degradation pathway prompts total degradation and mineralization of polymer. In any case, biodegradability relies on the microbial biofilm network formed in it. Biofilm community assumes a noteworthy role in altering the physicochemical properties and degradation of plastics. As biofilm offers bioavailability of supplements, sharing of metabolites without aggregation of metabolic products, brings about expanded cell life and degradation efficiency.

Further research is expected to altogether expand the various varieties of enzymes and microorganisms following up on these polymers. This can be accomplished by taking advantage of the *in silico* approach such as worldwide metagenomes of non-cultivated microorganisms and dark matter proteins. These types of researches will produce/identify novel enzymes and living beings that permit fast bio-degradation, reusing, or value aided utilization of most human-made polymers.

REFERENCES

Alexander H Tullo 2019 Plastic has a problem; is chemical recycling the solution? *C& En*; October 7, 2019 issue.

Anderson I C, Campbell C D, & Prosser J I, 2003. Diversity of fungi in organic soils under a moorland- Scots pine (*Pinus sylvestris* L.) gradient. *Environ. Microbiol.* 5(11), 1121–1132.

Anderson A, Grose J, Pahl S, Wyles K 2016. Microplastics in personal care products: Exploring perceptions of environmentalists, beauticians and students. *Marine Pollution Bulletin* 113(1).

Arutchelvi J, Sudhakar M, 2008. Biodegradation of polyethylene and polypropylene. *Indian J Biotechnol* 7(1):9–22.

Banerjee A 2019 https://www.bloombergquint.com/global-economics/india-is-generating-much-more-plastic-waste-than-it-reports-heres-why? Copyright © BloombergQuint

Barnes DKA, Galgani F, Thompson RC, Barlaz M, 2009. Accumulation and fragmentation of plastic debris in global environments. *Philos Trans Royal Soc* **364**1985–1998.

Barratt SR 2003 Fungi are the predominant micro-organisms responsible for degradation of soil-buried polyester polyurethane over a range of soil water holding capacities. *J Appl Microbiol* **95** 78–85

Bentham RH, Morton LHG, Allen NG, 1987. Rapid assessment of the microbial deterioration of polyurethanes. *Int Biodeterior* **23**377–386

Bharathidasan R and Prince L 2016 Biodegradation of low density polyethylene by bacteria from garbage soil in muthupet. *Glob. J. Res. Anal*. **5**, 3.

Bhardwaj H, Gupta R, Tiwari A, 2012. Microbial population associated with plastic degradation. *Sci Rep* **1(2)**1–4

Blettler, M, Ulla M, Rabuetti, A, Garello N, 2017. Plastic pollution in freshwater ecosystems: Macro-, meso-, and microplastic debris in a floodplain lake. *Environ. Monit. Assess***.** **189,** 581.

Bollinger A, Thies S, Katzke N, Jaeger KE, 2018.The biotechnological potential of marine bacteria in the novel lineage of *Pseudomonas pertucinogena*. *Microb Biotechnol* **13(1)** 19-31.

Brunner I, Fischer M, Ru¨thi J, Stierli B, Frey B, 2018. Ability of fungi isolated from plastic debris floating in the shoreline of a lake to degrade plastics. *PLOS ONE* **13(8)** 1-14.

Carniel A, Valoni E, Nicomedes J, Gomes

AD, de Castro AM, 2017. Lipase from *Candida antarctica* (CALB) and cutinase from *Humicola insolens* act synergistically for PET hydrolysis to terephthalic acid. *Process Biochem* **59**:84 90.

Da Luz JMR, Paes SA, Nunes MD, da Silva MCS, Kasuya MCM, 2013. Degradation of oxo-biodegradable plastic by *Pleurotus ostreatus*. *PLOS One*. **15;8(8)**:e69386.

Darby RT, Kaplan AM, 1968. Fungal Susceptibility of Polyurethanes.16: 900–905.
Boer DeW, Folman LB, Summerbell RC, Boddy L, 2005. Living in a fungal world: impact of fungi on soil bacterial niche development. *FEMS Microbiol Rev* **29(4)**795–811

Deepika S and Jaya M R 2015 Biodegradation of low density polyethylene by microorganisms from Garbage soil. *J. Exp. Bio. Agri. Sci*. **3(1)** 15–21.

Deguchi T, Kitaoka Y, Kakezawa M, Nishida T, 1998. Purification and Characterization of a Nylon Degrading Enzyme. Appl Environ Microbiol. **64** 1366–1371.

Derraik JGB 2002 The pollution of the marine environment by plastic debris: a review. *Mar Pollut Bull*.; **44** 842–852.

Devi R S 2016 The Role of Microbes in Plastic Degradation. *Environ.Waste Manage*. 341.

Dineshraj D and Ganesh P 2016. Screening and Characterization of Isolated Fungi from Plastic Waste Dump Yard Sites. *Int. J. Sci. Res*. **5,** 1.

Dress L 2010 iGEM : Synthetic biologists compete for the future. *Industrial Biotechnology* **6** 327–329.

El-Shafei H, El-Nasser NHA, Kansoh A L andAli A M 1998 Biodegradation of disposable polyethylene by fungi *Streptomyces species*. *Polym. Degrad. Stabil*. 62, 361–365.

Eriksen M, Lebreton LC, Carson HS, Thiel M, Moore CJ, Borerro JC, 2014. Plastic pollution in the world's oceans: more than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea. *PLoS ONE*.; **9(12)**e111913.

Eyerer P and Elsner P 1998 Using plastics to make new products. Journal of Polymer Engineering **18 (5)**, S 301-339.

Geyer R, Jambeck J R and Law K L 2017 Production, use, and fate of all plastics ever made. *Science Advances*, **3(7)** e1700782.

Gilan I, Hadar Y and Sivan A 2004 Colonization, biofilm formation and biodegradation of polyethylene by a strain of Rhodococcus rubber . *Appl. Microbiol. Biotechnol*. **65** 97–104.

Glass J E and Swift G 1989 Agricultural and synthetic polymers, biodegradation and utilization. *ACS Symposium Series 433. American Chemical Society. Washington DC,* 9–64.

Goldstein MC, Rosenberg M and Cheng L 2012 Increased oceanic microplastic debris enhances oviposition in an endemic pelagic insect. *Biol Lett*. **8:**817–820. pmid:22573831

Goodman C 2008 Engineering ingenuity at iGEM. *Nature Chemical Biology* **4:** 13.

Gu JD 2003 Microbiological deterioration and degradation of synthetic polymeric materials: Recent research advances. *International Biodeterioration & Biodegradation*.;**52**:69-91

Gu JD, Ford TE and Mitchell R 2000 Microbial corrosion of metals. *In: Revie, W. (Ed.), The Uhlig Corrosion Handbook, 2nd Edition.* Wiley, New York, 915–927.

Khan MR, Saha ML and Tabassum M, 2000. Biodegradation of polythene under natural conditions and the possible role of associated bacteria. *Bangl. J. Bot*. **29**105-108.

Hadad D, Geresh S and Sivan A 2005 Biodegradation of polyethylene by the thermophilic bacterium *Brevibacillus borstelensis* . *J. Appl. Microbiol.* **98**, 1093-1096.

Haernvall K, Zitzenbacher S, Wallig K, Yamamoto M, Schick MB, Ribitsch D and Guebitz GM 2017 Hydrolysis of ionic phthalic acid based polyesters by wastewater microorganisms and their enzymes. *Environ Sci Technol* **51** 4596–4605. doi:10.1021/acs.est.7b00062.

Haider T P, Völker C, Kramm J, Landfester K and Wurm F R 2019 Plastics of the Future? The Impact of Biodegradable Polymers on the Environment and on Society. *Angew. Chem. Int. Ed.* **58** 50-62.

Harms H, Schlosser D and Wick LY 2011 Untapped potential: exploiting fungi in bioremediation of hazardous chemicals. *Nat Rev Microbiol.* **9(3)** 177–192

Howard GT 2002 Biodegradation of polyurethane. *Int. Biodeter. Biodegr.* . **49** 245-252

Ibrahim N, Anwar M, Khalid M H, Ismail M S, and Hamzah M M 2011 Assessment of potential plastic-degrading fungi in Jordanian habitats. *Turk J Biol.* **35** 78-83

Jambeck JR, Geyer R, Wilcox C, Siegler TR, Perryman M and Andrady A 2015 Plastic waste inputs from land into the ocean. *Science*. **347:** 468–771.

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

Jensen BG, Andersen MR, Pedersen MH,

Frisvad JC and Sondergaard I 2010 Hydrophobins from Aspergillus species cannot be clearly divided into two classes. *BMC Res Notes*. :344.

Karolina VV, Sandra M, Martins F and Derlene AA 2019 Biodegradation of PCL and PVC: *Chaetomium globosum* (ATCC 16021) activity. *Folia Microbiologica* **64**1–7.

Keiko YO, Hiroshi M, Yuhji K and Yoshiki T 2001 Degradation of Polyethylene by a fungus, *Penicillium simplicissimum* YK. *Polymer Degradation and Stability* **72(2)**323-327.

Kim DY and Rhee YH 2003 Biodegradation of microbial and synthetic polyesters by fungi. *Appl. Micro. Biotech.* **61** 300–308.

Kodani S, Lodato MA, Durrant MC, Picart F, Willey JM And Sap T 2005 a lanthionine-containing peptide involved in aerial hyphae formation in the *Streptomycetes*. *Mol Microbiol*. **58** 368–1380.

Kohlmeier S, Smits THM, Ford RM, Keel C, Harms H and Wick LY 2005 Taking the fungal highway: mobilization of pollutant-degrading bacteria by fungi. *Environ Sci Technol* **39 (12)** 4640-4646.

Kolvenbach BA, Helbling DE, Kohler HE and Corvini PF 2014 Emerging chemicals and the evolution of biodegradation capacities and pathways in bacteria. *Curr Opin Biotechnol* **27** 8-14.

Kwan AH, Winefield RD, Sunde M, Matthews JM and Haverkamp RG 2006 Structural basis for rodlet assembly in fungal hydrophobins. *Proc Natl Acad Sci U S A.* **103** 3621-3626.

Linder MB, Szilvay GR, Nakari ST and Penttila ME 2005 Hydrophobins: the protein-amphiphiles of filamentous fungi. *FEMS Microbiol Rev*. **29** 877–896.

Littlejohna KA, Hooleyb P and Cox PW 2012

Bioinformatics predicts diverse Aspergillus hydrophobins with novel properties. Food Hydrocolloids. **27** 503–516.

Littlejohna KA, Hooleyb P and Cox PW 2012 Bioinformatics predicts diverse Aspergillus hydrophobins with novel properties. *Food Hydrocolloids*. **27** 503–516.

Lucas N, Bienaime C, Belloy C, Queneudec M, Silvestre F and Nava S JE 2008 Polymer biodegradation: mechanisms and estimation techniques-a review. *Chemosphere*. **73** 429–442.

Matavulj M and Molitoris HP, 1992. Fungal degradation of polyhydroxyalkanoates and a semiquantitative assay for screening their degradation by terrestrial fungi. **103 3**23–331.

Moore CJ 2008 Synthetic polymers in the marine environment: a rapidly increasing, long-term threat. *Environ Res*. 108:131–139.]

Muhamad W and Naimatul AW 2015 Microorganism as plastic biodegradation agent towards sustainable environment. *Adv Environ Biol*. **9** 8-13.

Murphy CA, Cameron JA, Huang SJ and Vinopal RT 1996 Fusarium Polycaprolactone Depolymerase Is Cutinase. **62** 456–460.

Mustalahti E, Saloheimo M and Joensuu JJ 2011 Intracellular protein production in *Trichoderma reesei* (*Hypocrea jecorina*) with hydrophobin fusion technology. *N Biotechnol*. **30(2)** 262-8.

Negoro S 2012 Three-dimensional Structure of Nylon Hydrolase and Mechanism of Nylon-6 Hydrolysis. **287** 5079–5090.

Nunes MD, Da Luz JMR, Paes AS, Torres DP and Kasuya MCM 2014 Jatropha seed cake supplementation for improved fungal growth and later use as animal feed. *African Journal of Microbiology Research*. **8(38)** 3457-3462.

Oliveira SF, Da Luz JMR, Kasuya MCM, Ladeira, LO, Correa AJ, 2018. Enzymatic extract containing lignin peroxidase immobilized on carbon nanotubes: Potential biocatalyst in dye decolourization. *Saudi Journal of Biological Sciences* **25** 651-659

Purnomo AS, Mori T, Kamei I, Nishii T and Kondo R 2010 Application of mushroom waste medium from *Pleurotus ostreatus* for bioremediation of DDT-contaminated soil. *International Biodeterioration & Biodegradation*. **64** 397-402

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

Raj HG, Saxena M, Allameh A, 1992. *In: Arora DK, Elander RP, Mukerji KG (eds) Handbook of applied mycology. Marcel Dekker, New York*, pp 881–904

Russell JR 2011 Biodegradation of polyester polyurethane by endophytic fungi. *Appl Environ Microbiol*. **77** 6076–6084.

Sato S, Saika A, Shinozaki Y, Watanabe T, Suzuki K and Sameshima Y Y 2017 Degradation profiles of biodegradable plastic films by biodegradable plastic-degrading enzymes from the yeast *Pseudozyma antarctica* and the fungus *Paraphoma sp.* B47-9. Polymer Degradation and Stability. **141** 26-32.

Shah AA, Hasan F, Hameed A and Ahmed S 2008 Biological degradation of plastics: a comprehensive review. *Biotechnol Adv*. **26** 246–265.

Shah AA 2015 Degradation of poly (ε-caprolactone) by a thermophilic bacterium *Ralstonia sp.* strain MRL-TL isolated from hot spring. *Int. Biodeteri. Biodegr.* **98** 35–42.

Singh B and Sharma N 2008 Mechanistic implications of plastic degradation. *Polym Degrad Stab*. **93** 561–584.

Sivan A, Szanto M and Pavlov V 2006 Biofilm development of the polyethylene degrading bacterium *Rhodococcus rubber*. *Appl. Microbiol. Biotech.* **72** 346–352.

Song JH, Murphy RJ, Narayan R and Davies GB 2009 Biodegradable and compostable alternatives to conventional plastics. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences* **364 (1526)** 2127–2139.

Sunde M and Kwan AH 2008 Templeton MD, Beever RE, Mackay JP. Structural analysis of hydrophobins. *Micron*. **39** 773–784.

Thompson RC, Moore CJ, Vom Saal FS and Swan SH 2009 Plastics, the environment and human health: current consensus and future trends. *Philos Trans Royal Soc B*. **364** 2153−2166.

Tokiwa Y, Calabia BP, Ugwu CU and Aiba S 2009 Biodegradability of plastics," *Int J Mol Sci*. **10** 3722–3742.

Van Sebille E, Wilcox C, Lebreton L, Maximenko N, Hardesty BD and Franeker JA, 2015 A global inventory of small floating plastic debris. *Environ Res Lett*. **10** 124006.

Wainwright M, 1993. *In: Jennings DH (ed) Stress tolerance of fungi. Marcel Dekker,* New York, pp 127–144

Wessels J, De Vries O, Asgeirsdottir SA, Schuren F, 1991. Hydrophobin Genes Involved in Formation of Aerial Hyphae and Fruit Bodies in Schizophyllum. *Plant Cell.* **3** 793–799.

Wessels JG 1997 Hydrophobins: proteins that change the nature of the fungal surface. *Adv Microb Physiol*. **38** 1–45.

Williams DF 1981 Enzymic hydrolysis of polylactic acid. *Engineering in Medicine*. **10** 5–7.

Yamada O K, Mukumoto Y, Katsuyaya Y, Saiganji A and Tani Y 2001 Degradation of polyethylene by a fungus *Penicillium simplicissimum* YK. *Poly. Degrad Stabil.* **72** 323–327.

Zafar U, Houlden A and Robson GD 2013 Fungal communities associated with the biodegradation of polyester polyurethane buried under compost at different temperatures. *Appl Environ Microbiol* **79** 7313–7324.

Zbyszewski M, Corcoran PL and Hockin A 2014 Comparison of the distribution and degradation of plastic debris along shorelines of the Great Lakes, North America. *J Great Lakes Res*. **40** 288–299.