International Journal of Trend in Scientific Research and Development (IJTSRD)
International Open Access Journal
ISSN No: 2456 - 6470 | www.ijtsrd.com | Volume - 2 | Issue – 3

Biodegradation of Plastic by *AspergillusSP*

Kannahi M, Thamizhmarai T
PG and Research Department of Microbiology, S.T.E.T Women's College,
Sundarakkottai, Mannargudi (TK), Thiruvarur (DT), Tamil Nadu, India

ABSTRACT

Plastics are light weighted, durable, corrosion resistant materials, strong, and inexpensive. Scientists have reported many adverse effects of the plastic in the environment and human health. Nowadays biodegradable plastics are considered as the environmental friendly. The plastic polymers as such at room temperatures are not considered as toxic. The toxic properties are found in plastics, when heat is released from the food material in which they are covered and then they produce serious human health problems. This review articles covers the list of biodegradation of plastics, some factors that affect their biodegradability, plastic types and their application and plastic degrading by fungi are discussed.

Keywords: *Plastic; Biodegradation; Aspergillus; enzymatic degradation*

INTRODUCTION:

Plastics are polymers derived from petrochemicals which are further synthetically made from monomers by some chemical processes to produce these long chain polymers [Shimao M., 2001]. Plastics are light weight, low cost, highly durable and are of high strength. In our dailylife the plastics are available in various forms such as nylon, polycarbonate, polyethylene-terephthalate, polyvinylidene chloride, Urea formaldehyde, polyamides, polyethylene, polypropylene, polystyrene, polytetraflouroethylene, polyurethane and polyvinyl chloride [Smith ,1964]. The annual production of plastics has doubled over the past 15 years to 245 million tonnes Production of plastic has increased from 204 million tonnes in 2002 million tonnes in 2013, representing a 46.6 % increase 2015. During the past three decades, plastic materials are widely used in transportation, food, clothing, shelter construction, medical and recreation industries, fishing nets, packaging, food industry and agricultural field [Anbuselvi et al., 2014].

Under the natural condition degradable or non-degradable organic materials are considered as the major environmental problem, *e.g.* plastics. The accumulation of these plastic wastes created serious threat to environment and wild life [Takabatake et al., 2003]. The environmental concerns include air, water and soil pollution. The dispersal of urban and industrial wastes contaminates the soil. The soil contaminations are mainly made by human activities [Ghosh,2005]. Environmental pollution is caused by synthetic polymers, such as wastes of plastic and water-soluble synthetic polymers in wastewater [Premrajet al., 2005].

Many animals die of waste plastics either by being caught in the waste plastic traps or by swallowing the waste plastic debris to exert ruinous effects on the ecosystem [Usha et al.,2011]**.** Some of the plastic products cause human health problems because they mimic human hormone. Vinyl chloride is classified by the International Agency for the Research on Cancer (IARC) as carcinogenic to humans [Rudel Ruthann et al., 2007]. It has also shown to be a mammary carcinogen in animals. PVC is used in numerous consumer products, including adhesives, detergents, lubricating oils, solvents, automotive plastics, plastic clothing, personal care products (such as soap, shampoo, deodorants fragrances, hair spray, nail polish) as well as toys and building materials.

[IARC.,2011] Styrene is classified by IARC as possibly carcinogenic to humans and is shown to cause mammary gland tumours in animal studies. It also acts as an endocrine disrupter [Gray et al.,2009]. BPA has been linked with premature birth, intrauterine growth retardation, preeclampsia and still birth [Benachour, 2009]. It has also been noted that prolonged exposure to BPA shows a significant effect on the sex hormones (progesterone) in females [Hao et al., 2011]. Burning plastics usually produce some toxoids gases like furans and dioxins which are dangerous greenhouse gases and play an important role in ozone layer depletion. In fact, dioxins cause serious problems in the human endocrine hormone activity, thus becoming a major concern for the human health [Pilz et al., 2010]. Dioxins also cause very serious soil pollution, causing a great concern for scientific community worldwide. Phthalates and Biphenyl are closely related in thyroid causing disfunction in humans.

BIODEGRADATION:

The metabolic diversity of bacteria makes them a useful resource for remediation of pollution in the environment [Iranzo et al., 2001]. Bacteria have been utilised in the clean-up of oil spills [Head et al.,1999], PCBs [Luigi, 2007] and heavy metals, such as arsenic, mercury, cadmium and lead [De et al., 2008]. There are sufficient examples to suggest there are few if any substances that cannot be utilised at least in part by microbes for metabolic activities [Iranzo, 2001]. Biodegradation is an attractive alternative to current practices for waste disposal, as it is generally a cheaper process, potentially much more efficient and does not produce secondary pollutants, such as those associated with incineration and landfill [Swannell et al., 1999]. In some cases, it may even be possible to obtain useful end products with economic benefit from bacterial metabolism of pollutants, for example, ethanol for use in biofuels [Iranzo, 2001].

Bioremediation of hydrocarbons, crude oil, for example, poses a number of practical difficulties. Bacteria prefer aqueous nutrients [Iranzo, 2001] and hydrocarbons are often immiscible with water. Also, hydrocarbons are largely deficient in certain essential elements, namely nitrogen, potassium and phosphorus [Rosa, 2007]. It has been shown in the literature that manually adding these elements in the form of fertiliser or ammonium sulphate can significantly aid the degradation of hydrocarbons by bacteria [Rosa, 2007]. Hydrocarbons also actively interfere with cell membranes, accumulating within and disrupting the phospholipid bilayer [Pieper, 2000], however, some bacteria have even been isolated that resist organic solvents.

Many studies have investigated the degradability of a wide range of polymers [Yamada-Onodera, 2001]. [Zheng, 2005] observed that in most cases, polymers with pure carbon backbones are particularly resistant to most methods of degradation, but polymers that include heteroatoms in the backbone (e.g., polyesters, polyamines) show higher susceptibility to degradation. While this is often true, there is, however, a secondary qualifier in the latter case; aromatic polymers tend to be resistant to degradation, despite the presence of bonds that are normally readily hydrolysed [Müller, 2001]. PET is a classic example of such a polymer;the ester bonds that form part of the polymer chain could normally be quite easily broken by a number of mechanisms, however, due to its aromatic groups, the polymer is essentially non-degradable under normal conditions.

Biodegradable Polymers

Over the last ten years, there has been a shift away from investigation of the degradability of traditional plastics, with more and more emphasis placed on the development of novel biodegradable polymers. Many biodegradable polymers currently exist, both natural and synthetic, however, the two major barriers to their incorporation in current plastic-based applications are increased production costs and inferior material properties, e.g., decreased durability [Amass,1998]. Production costs can be minimised through the continued development of manufacturing protocols and increasing efficiency, but substantial research is still required to produce biodegradable polymers with comparable physical properties to conventional plastics. Regardless, some progress has been made in the field of biodegradable plastics, and a number of strategies have emerged for their development.

One approach for production of biodegradable plastics is to produce materials based on conventional plastics with enhanced degradability, without compromising the material properties. For example, polymers with additional functional groups on the polymer chains have been produced by both post-polymerisation treatments [Artham, 2009] and copolymerisation with equivalent functionalised monomers [Marqués-Calvo, 2006]. The rationale behind this is to create increased opportunities for microbial enzymes to attack the polymer chains. However, biodegradation of these polymers is still relatively limited, and for degradation to occur, there is a requirement for substantial energy input, especially for the post-polymerisation treated materials. Better degradation rates have been achieved when producing block copolymers of conventional plastics with readily hydrolysable polymeric molecules. Common examples are starch, lactic acid, ethylene glycol and caprolactone [Raquez, 2011]. Unfortunately, these types of polymers are significantly less durable than many conventional plastics, and in many cases, it is unclear whether these polymers are truly biodegraded or whether they simply disintegrate into small pieces.

Development of plastics based on biological molecules has been a popular area of research. Polymers have been produced based partially or entirely on starch [Russo, 2009], lactic acid [Ye, 2011],caprolactone [Verbeek, 2010], proteins [Puls,2011], cellulose acetate [Ghasemlou, M.;2011] and other polysaccharides [Nitschke, 2011], and in many cases, the mechanical durability of these polymers has been improved through addition of plasticisers [Nitschke, 2011] or nanoparticles [Verbeek, 2010] or by carefully controlling production conditions [Brandelero, 2011]. One of the most significant groups of biopolymers is poly(hydroxyalkanoates) (PHAs). PHAs are polymeric materials naturally produced by many bacteria and some archaea, which can be processed into a number of forms suitable for packaging, coatings and biomedical applications [Chen, 2009]. PHAs are produced commercially through bacterial fermentation, although quantities are somewhat limited due to inflated production expenses in comparison to conventional plastics and the lack of high-value applications [Kunasundari, 2011]. Manufacturers have been able to decrease expenses to some degree by utilising cheaper foodstocks for metabolism by bacteria; PHAs can be produced from waste materials, such as whey, wheat and rice bran, molasses, vegetable oil and even carbon dioxide [Kunasundari, 2011], however, the main prohibitive expense remains the extraction procedure for recovery of the polymer [Kunasundari, 2011]. Extraction methods include solvent extraction, chemical digestion, enzymatic treatment, mechanical disruption, supercritical fluid disruption, flotation, gamma irradiation and two-phase systems, however, as of yet, no sufficiently inexpensive extraction technique has been developed to allow PHAs to truly compete with conventional plastics in terms of market share [Kunasundari, 2011].

Factors Affecting the Biodegradability of Plastics

The properties of plastics are associated with their biodegradability. Both the chemical and physical properties of plastics influence the mechanism of biodegradation. The surface conditions (surface area, hydrophilic, and hydrophobic properties), the first order structures (chemical structure, molecular weight and molecular weight distribution) and the high order structures (glass transition temperature, melting temperature, modulus of elasticity, crystallinity and crystal structure) of polymers play important roles in the biodegradation processes.

In general, polyesters with side chains are less assimilated than those without side chains [Tokiwa, 1976]. The molecular weight is also important for the biodegradability because it determines many physical properties of the polymer. Increasing the molecular weight of the polymer decreased its degradability. PCL with higher molecular weight (Mn > 4,000) was degraded slowly by *Rhizopus delemar* lipase (endo-cleavage type) than that with low Mn [43]. Moreover, the morphology of polymers greatly affects their rates of biodegradation. The degree of crystallinity is a crucial factor affecting biodegradability, since enzymes mainly attack the amorphous domains of a polymer. The molecules in the amorphous region are loosely packed, and thus make it more susceptible to degradation. The crystalline part of the polymers is more resistant than the amorphous region. The rate of degradation of PLA decreases with an increase in crystallinity of the polymer [Tsuji, 1998]. The melting temperature (Tm) of polyesters has a strong effect on the enzymatic degradation of polymers. The higher the Tm, the lower the biodegradation of the polymer [Swift, 1998]. The chemical structures of aliphatic polyester, polycarbonate, polyurethane and polyamides, together with their (Tm) are listed in Table 1.

Table 1: Chemical structures of aliphatic polyester, polycarbonate, polyurethanes andpolyamides with their (Tm)

Name	Chemical Structure	Tm (°C)
Polyester	$-O-(CH_2)_6-O-CO-(CH_2)_4-CO-$	60
Polycarbonate	$-O-(CH_2)_4-O-CO-O-(CH_2)_4-O-CO-$	65
Polyurethane	$-NH-(CH_2)_6-NH-CO-O-(CH_2)_4-O-CO-$	180
Polyamide	$-NH-(CH_2)_6-NH-CO-(CH_2)_6-CO-$	240
Polyamide	$-NH-(CH_2)_6-NH-CO-(CH_2)_4-CO-$	265

Involvement of microorganisms for degradation of plastics:

The microorganism's role is very important for plastic degradation. The different types of microbes degrade different groups of plastics. The microbial biodegradation has been at accepted and process still underway for its enhanced efficiency. Table 2 shows the list of microorganisms and their plastic degrading efficiencies.

Table 2: Table showing different microbes and their plastic degrading efficiencies

Microorganisms	Types of plastics	Source of the microbes	Degradation Efficiency	Reference
Aspergillus sp	(LDPE)	Not Specified	22%	72
Aspergillus glaucus	Polythene and Plastic	Mangrove soil	20.80% and 7.26%	73
	Polythene bags and plastic cups polythene carry bags	Mangroves rhizosphere soil	20.54±0.13 28.80±2.40%	74
Aspergillus niger	Polythene bags and plastic cups	Medicinal Garden soil	12.25% and 12.5%	75
	powdered LDPE	Not Specified	5% and 11.07%	76
Aspergillus oryzae	(HDPF)	buried soil	72%	77
Aspergillus flavus	Low density Polythene Powder Disposable plastic Films	Nile river delta	28.5% and 46.5%	78
Aspergillus versicolor	LDPE in the Powdered form	sea water	4.1594g/L	79

Plastic degrading by fungi:

The growth of many fungi can also cause small-scale swelling and bursting, as the fungi penetrate the polymer solids. In recent yearsfungal strains have been reported for plastic degradation such as *Aspergillus versicolar*[Pramila , 2011], *Aspergillus flavus* [Sowmya, 2012],*Chaetomium*spp [Oda, 1995]*Mucor circinellodies* species etc. The polythenebags were degraded by some fungal species identified such as, *Aspergillus niger, A.ornatus, A.nidulans, A. cremeus, A. flavus, A. candidus and A. glaucus* were the predominantspecies. The microbial species are associated with the degrading materials were identified fungi (*Aspergillus niger, Aspergillus glaucus*), [Pramila,2011]. Sanchez *et al*., [Szumigaj, 2008] has reported that the PCL-degrading fungi, *Aspergillussp* is effective in biodegradation as plastics studies. Many studies on fungal degradation of the bio plastic have also been performed including

Paecilomyces lilacinus D218 [Torres,1996], *Fusarium moniliforme Fmm* [Benedict, 1983], *Aspergillus flavus* ATCC9643 [Jarerat ,2001], *Thermoascus aurantiacus*IFO31910 [Szumiga, 2008], *Tritirachium album* ATCC22563 [Li et al., 2011], *Paecilomyces verrucosum* [Mogil`nitskii,1987] and*Aspergillus sp*.XH0501-a [Mogil`nitskii,1987].On the otherhand, polylactic acid (PLA) is subjected to degradation by only two genera of fungi (*Penicillium roqueforti* and *Tritirachium album*) [Ibrahim ,2011] reported that*Aspergillus niger*vanTieghem F-1119 had the ability to degrade PVC. PHB and polyesters are degraded by many fungal genera such as, *Fusarium, Mucor, Paecilomyces, Penicillium, Pullularia, Rhodosporidium,* and *Verticillium*. Similarly, is degradeby *Aspergillus, Aureobasidium, Chaetomium, Cryptococcus, Fusarium, Rhizopus, Penicillium, and Thermoascus*. PEA is degraded by *Aspergillus, Aureobasidium, Penicillium, Pullularia*.Fungus like*Alternaria solani, Spicariasp., Aspergillus terreus, Aspergillusfumigates, Aspergillus flavus* were isolated from soil whereplastic have been dumped. These caused significant weight loss in the PS PUR blocks in the shaken cultures, reaching up to 100% in case of the isolate *Fusarium solani* [Canché-Escamilla, 2011].

CONCLUSION

Many studies showed the striking effect of plastic waste on the aquatic and marine ecosystem, and thus, it has become one of the major problems for the modern environmentalist. To the get rid of such a menace, people usually put them in landfills or burn it, but both these practices cause very serious threats to the environment and the ecosystem. Some plastics are designed to be biodegradable and can be broken down in a controlled environment such as landfill. Biodegradation of waste plastic is an innovative are of research solving many environmental problems. This review discusses on the literature of microbes used for biodegradation of plastic waste. Most of the plastic wastes are degrade by the microorganisms. Based on these literatures available one could conclude that in order to enhance biodegradation of plastics waste the following approaches could be adopted as the biodegradation studies of plastics in dumped soil.

REFERENCES

1. Shimao M. Biodegradation of plastics. Current Opinion in Biotechnology 2001; 12: 242-247.
2. Smith WM. Manufacture of plastic. USA: Technology and Engineering, Reinhold Pub. Corp; 1964.
3. Plastics Europe, Compelling facts about plastics. An analysis of European plastics production, demand and recovery for 2008. Brussles: Plastics Europe 2009; p 29.
4. Plastic Europe, An analysis of European plastics production demand and waste data. Belgium: EPRO; 2015.
5. Vatseldutt, Anbuselvi S. Isolation and Characterization of Polythene Degrading Bacteria from Polythene Dumped Garbage. Int J Pharm 2014; 25(2): 205-206.
6. Chua ASM, Takabatake H, Satoh H and Mino T. Production of polyhydroxyalkanoates (PHA) by activated sludge treating municipal waste water: Effect of pH, Sludge Retention Time (SRT), and Acetate Concentration influent. Water Res 2003; 37(15):360-361.
7. Ghosh M, Singh SP. A review on phytoremediation of heavy metals and utilization of its by products. Appl Environ 2005; 3: 1-18
8. Premraj R, Mukesh CD. Biodegradation of polymer. Indian J Biotech 2005; 4: 186-189.
9. Rudel Ruthann A, Attfield RK, Schifano JNand Brody JG. Chemicals causing mammary gland tumors in animals signal new directions for epidemiology, chemicals testing and risk assessment for breast cancer prevention. Cancer 2007; 109(1): 2635-2666,
10. IARC (International Agency for the Research on Cancer). Agents classified by the IARC monographs. Lyon, France: World Health Organization; 2011; p 321.
11. Gray J, Evans N, Taylor B, Rizzo, JJ, Walker M. State of the evidence: The connection between Breast Cancer and the Environment, Int J Occu Environ Heal 2009; 15 (1): 43-78.
12. Benachour N, Aris A. Toxic effects of low doses of bisphenol-a on human placental cells. Toxicol Appl Pharmacol 2009; 241(3): 322-328.

13. Hao J, Wang J, Zhao W, Ding L, Gao E and Yuan W. Effect of bisphenol a exposure on sex hormone level in occupational women. Wei Sheng Yan Jiu 2011; 40(3):312-214.
14. Pilz H, Brandt B, Fehringer R. The impact of plastics on life cycle energy consumption and greenhouse gas emissions in Europe, summary report. Vienna, Austria: Denkstatt GmbH; 2010.
15. The source of this information is a press release of No Plastics in the Environment(NoPE) titled 'Imports Versus Surplus: A Glut of Plastics in India Today', 10 January2002. Courtesy Bharati Chaturvedi, Director, Chintan Environmental Organisation, New Delhi.
16. Iranzo, M.; Sainz-Pardo, I.; Boluda, R.; Sánchez, J.; Mormeneo, S. The use of microorgansims in environmental remediation. *Ann. Microbiol.***2001**, *51*, 135–143.
17. Head, I.M.; Swannell, R.P.J. Bioremediation of petroleum hydrocarbon contaminants in marine habitats. *Curr. Opin. Biotechnol.***1999**, *10*, 234–239.
18. Rosa, A.P.; Triguis, R.P.J. Biomediation process on Brazil Shoreline. Laboratory experiments. *Environ. Sci. Pollut. Res* **2007**, 14, 470-476.
19. Piedad Díaz, M.; Boyd, K.G.; Grigson, S.J.W.; Burgess, J.G. Biodegradation of crude oil across a wide range of salinities by an extremely halotolerant bacterial consortium MPD-M, immobilized onto polypropylene fibers. *Biotechnol. Bioeng.***2002**, *79*, 145–153.
20. Hazen, T.C.; Dubinsky, E.A.; DeSantis, T.Z.; Andersen, G.L.; Piceno, Y.M.; Singh, N.; Jansson, J.K.; Probst, A.; Borglin, S.E.; Fortney, J.L.; Stringfellow, W.T.; Bill, M.; Conrad, M.E.; Tom, L.M.; Chavarria, K.L.; Alusi, T.R.; Lamendella, R.; Joyner, D.C.; Spier, C.; Baelum, J.; Auer, M.; Zemla, M.L.; Chakraborty, R.; Sonnenthal, E.L.; D'haeseleer, P.; Holman, H.-Y.N.; Osman, S.; Lu, Z.; van Nostrand, J.D.; Deng, Y.; Zhou, J.; Mason, O.U. Deep-sea oil plume enriches indigenous oil-degrading bacteria. *Science***2010**, *330*, 204–208.
21. Luigi, M.; Gaetano, D.M.; Vivia, B.; Angelina, L.G. Biodegradative potential and characterization of psychrotolerant polychlorinated biphenyl-degrading marine bacteria isolated from a coastal station in the Terra Nova Bay (Ross Sea, Antarctica). *Mar. Pollut. Bull.***2007**, *54*, 1754–1761.
22. De, J.; Ramaiah, N.; Vardanyan, L. Detoxification of toxic heavy metals by marine bacteria highly resistant to mercury. *Mar. Biotechnol.***2008**, 10, 471–477.
23. Takeuchi, M.; Kawahata, H.; Gupta, L.P.; Kita, N.; Morishita, Y.; Ono, Y.; Komai, T. Arsenic resistance and removal by marine and non-marine bacteria. *J. Biotechnol.***2007**, *127*, 434–442.
24. Pieper, D.H.; Reineke, W. Engineering bacteria for bioremediation. *Curr. Opin. Biotechnol.***2000,** *11*, 262–270.
25. Yamada-Onodera, K.; Mukumoto, H.; Katsuyaya, Y.; Saiganji, A.; Tani, Y. Degradation of polythene by a fungus, *Penicillium simplicissimum* YK. *Polym. Degrad. Stabil.***2001,** 72, 323-327.
26. Zheng, Y.; Yanful, E.K.; Bassi, A.S. A review of plastic waste biodegradation. *Crit. Rev.Biotechnol* **2005**, *25*, 243–250.
27. Bonhomme, S.; Cuer, A.; Delort, A.-M.; Lemaire, J.; Sancelme, M.; Scott, G. Environmental degradation of polyethylene. *Polym. Degrad. Stabil.***2003**, *81*, 441–452.
28. Müller, R.-J.; Kleeberg, I.; Deckwer, W.-D. Biodegradation of polyesters containing aromatic constituents. *J.Biotechnol.* **2001**, *86*, 87–95.
29. Zhang, J.; Wang, X.; Gong, J.; Gu, Z. A study on the biodegradability of polyethylene terephthalate fiber and diethylene glycol terephthalate. *J. Appl. Polym. Sci.***2004**, *93*, 1089–1096.
30. Müller, R.-J.; Schrader, H.; Profe, J.; Dresler, K.; Deckwer, W.-D. Enzymatic degradation of poly(ethylene terephthalate): rapid hydrolyse using a hydrolase from *T. fusca*. *Macromol. Rapid Comm.* **2005,** *26,*1400-1405.
31. Herzog, K.; Müller, R.-J.; Deckwer, W.-D. Mechanism and kinetics of the enzymatic hydrolysis of polyster nanoparticles by lipases *Polym. Degrad. Stabil* **2006**, *91*, 2486–2498.
32. Artham, T.; Doble, M. Biodegradation of physicochemically treated polycarbonate by fungi. *Biomacromolecules* **2009***, 11,* 20-28.
33. Kondratowicz, F.L.; Ukielski, R. Synthesis and hydrolytic degradation of poly(ethylene succinate) and poly(ethylene terephthalate) copolymers *Polym. Degrad. Stabil.***2009,***94,*375-382.

34. Amass, W.; Amass, A.; Tighe, B. A review of biodegradable polymers: Uses, current developments in the synthesis and characterization of biodegradable polyesters, blends of biodegradable polymers and recent advances in biodegradation studies. *Polym. Int.***1998**, *47*, 89–144.

35. Marqués-Calvo, M.S.; Cerdà-Cuéllar, M.; Kint, D.P.R.; Bou, J.J.; Muñoz-Guerra, S. Enzymatic and microbial biodegradability of poly(ethylene terephthalate) copolymers containing nitrated units. *Polym. Degrad. Stabil* **2006***,91,* 663-671.

36. Raquez, J.-M.; Bourgeois, A.; Jacobs, H.; Degée, P.; Alexandre, M.; Dubois, P. Oxidative degradations of oxodegradable LDPE enhanced with thermoplastic pea starch: thermo- mechanical properties, morphology, and UV-ageing studies. *J. Appl. Polym. Sci.***2011**, *122*, 489-496.

37. Kint, D.; Muñoz-Guerra, S. A review on the potential biodegradability of poly(ethylene terephthalate). *Polym. Int.***1999**, *48*, 346–352.

38. Russo, M.A.L.; O'Sullivan, C.; Rounsefell, B.; Halley, P.J.; Truss, R.; Clarke, W.P. The anaerobic degradability of thermoplastic starch: Polyvinyl alcohol blends: Potential biodegradable food packaging materials. *Bioresour. Technol.***2009**, *100*, 1705–1710.

39. Brandelero, R.P.H.; Grossmann, M.V.E.; Yamashita, F. Effect of the method of production of the blends on mechanical and structural properties of biodegradable starch films produced by blown extrusion. *Carbohydr. Polym.***2011**, *86*, 1344-1350.

40. Kim, S.H.; Tan, J.P.K.; Fukushima, K.; Nederberg, F.; Yang, Y.Y.; Waymouth, R.M.; Hedrick, J.L. Thermoresponsive nanostructured polycarbonate block copolymers as biodegradable therapeutic delivery carriers. *Biomaterials***2011**, *32*, 5505–5514.

41. Tokiwa, Y.; Ando, T.; Suzuki T. Degradation of polycaprolactone by a fungus. *J. Ferm.Technol,* **1976,***54,*603-608.

42. Tokiwa, Y.; Suzuki, T. Hydrolysis of polyesters by Rhizopus delemar lipase. *Agric.Biol.Chem.* **1978,** *42,* 1071-1072. *Macromolecules* **1998**,*31*, 2461-2467.

43. Tsuji, H.; Miyauchi, S. Poly(L-lactide) 6. Effects of crystallinity on enzymatic hydrolysis of poly(l-lactide) without free amorphous region. *Polym. Degrad. Stab.* **200**1, *71*, 415-424.

44. Tokiwa, Y.; Suzuki, T. Hydrolysis of copolyesters containing aromatic and aliphatic ester blocks by lipase. *J. Appl. Polym*. *Sci.***1981**, *26*, 441-448.

45. Tokiwa, Y.; Suzuki, T.; Ando, T. Synthesis of copolyamide-esters and some aspects involved in their hydrolysis by lipase *J. Appl. Polym. Sci.***1979**, *24*, 1701-1711.

46. Swift G. Handbook of biodegradable polymers. CRC Press; 1998.

47. Pramila R, Ramesh KV. Biodegradation of LDPE by fungi isolated from municipal landfill area, J. Microbiol. Biotechnol Res 2011; 1(2): 131-136.

48. Pramila R, Ramesh K. Biodegradation of LDPE by fungi isolated from marine water a SEM analysis. Afr J Microbiol Res 2011; 5(2): 5013-5018.

49. Sowmya HV, Ramalingappa M, Krishnappa M. Degradation of polyethylene by

50. *Chaetomium* sp. and *Aspergillus flavus.* Int JRec Sci Res 2012; 3(1): 513-517.

51. Oda Y, Asari H, Urakami T, Tonomura K. Microbial degradation of poly(3-hydroxybutyrate) and polycaprolactone by filamentous fungi. J Ferment Bioeng 1995; 80: 265–269.

52. Torres A, Li SM, Roussos S, Vert M. Screening of microorganisms for biodegradation of poly (lactic acid) and lactic acid-containing polymers. Appl Environ Microbiol 1996; 62:2393–2397.

53. Benedict CV, Cook WJ, Jarrett P, Cameron JA, Huang SJ, and Bell JP. Fungal degradation of polycaprolactones. J Appl Polym Sci 1983; 28: 327–334.

54. Sanchez J, Tsuchii A, Tokiwa Y. Degradation of polycaprolactone at 50°C by a thermotolarant Aspergillus sp. Biotechnol Lett 2000; 22: 849–853.

55. Jarerat A, Tokiwa Y. Degradation of poly (L-lactide) by a fungus. Macromol Biosci 2001; 1: 136–140.

56. Szumigaj J, Zakowaka Z, Klimek L, Rosicka-Kaczmarek J, Bartkowiak A. Assessment of polylactide foil degradation as a result of filamentous fungi activity. Pol J Environ Stud 2008; 17: 335-341.

57. Li F, Hu X, Guo Z, Wang Z, Wang Y, Liu D, Xia H, Chen S. Purification and characterization of a novel poly (butylenes succinate)-degrading enzyme from Asperillus sp. J Microbiol Biotechnol 2011; 27:2591-2596.

58. Mogil`nitskii GM, Sagatelyan RT, Kutishcheva TN, Zhukova SV, Kerimov SI, Parfenova TB. Disruption of the protective properties of the polyvinyl chloride coating under the effect of microorganisms. Prot Met (Engl Transl) 1987; 23: 173–175.

59. Ibrahim D, Bankole OC, Ma'aji SA, Ohize EJ and Abdul BK. Assessment of the Strength Properties of Polystyrene Material used in Building Construction in Mbora District Of Abuja, Nigeria. Int J Engg Res Dev 2013; 6(12): 80-84.

60. Canché-Escamilla, G.; Canché-Canché, M.; Duarte-Aranda, S.; Cáceres-Farfán, M.; Borges-Argáez, R. Mechanical properties and biodegradation of thermoplastic starches obtained from grafted starches with acrylics. *Carbohydr. Polym.* **2011**, *86*, 1501–1508.

61. Nampoothiri, K.M.; Nair, N.R.; John, R.P. An overview of the recent developments in polylactide (PLA) research. *Bioresour. Technol.* **2010**, *101*, 8493–8501.

62. Ye, R.-R.; Wang, Z.-Y.; Wang, Q.-F.; Yang, K.; Luo, S.-H. Synthesis of biodegradable material poly(lactic acid-co-aspartic acid) via direct melt polycondensation and its characterization. *J.Appl. Polym. Sci.* **2011**, *121*, 3662–3668.

63. Neppalli, R.; Causin, V.; Marega, C.; Saini, R.; Mba, M.; Marigo, A. Structure, morphology and biodegradability of poly(ε-caprolactone)-based nanocomposites. *Polym. Eng. Sci.* **2011**, *51*, 1489–1496.

64. Verbeek, C.; van den Berg, L.E. Extrusion processing and properties of protein-based thermoplastics. *Macromol. Mater. Eng.* **2010**, *295*, 10–21.

65. Puls, J.; Wilson, S.A.; Hölter, D. Degradation of cellulose acetate-based materials: A review. *J.Polym. Environ.* **2011**, *19*, 152–165.

66. Ghasemlou, M.; Khodaiyan, F.; Oromiehie, A.; Yarmand, M.S. Development and characterisation of a new biodegradable edible film made from kefiran, an exopolysaccharide obtained from kefir grains. *Food Chem.* **2011**, *127*, 1496–1502.

67. Nitschke, M.; Costa, S.G.V.A.O.; Contiero, J. Rhamnolipids and PHAs: Recent reports on *Pseudomonas*-derived molecules of increasing industrial interest. *Process Biochem.* **2011**, *46*,621–630.

68. Chen, G.-Q. A microbial polyhydroxyalkanoates (PHA) based bio- and materials industry. *Chem.Soc. Rev.* **2009**, *38*, 2434–2446.

69. Akaraonye, E.; Keshavarz, T.; Roy, I. Production of polyhydroxyalkanoates. The future green materials of choice. *J. Chem. Technol. Biotechnol.* **2010**, *85*, 732–743.

70. Kunasundari, B.; Sudesh, K. Isolation and recovery of microbial polyhydroxyalkanoates. *ExpressPolym. Lett.* **2011**, *5*, 620–634.