PAKISTAN JOURNAL OF HEALTH SCIENCES

https://thejas.com.pk/index.php/pjhs

Volume 3, Issue 4 (September 2022)

Review Article

The Efficacy of Microbes in the Detoxification of Industrial Effluent and Curbing of their Impact on Environment

Humaira Niamat[1*], Arqam Tahir[1], Muhammad Abdullah Zahid[1], Muhammad Danyal Mustafa[1] and Ali Ahmad[1]

[1]Department of Biology, Lahore Garrison University, Pakistan

ARTICLE INFO

Key Words:

Industrial Effluent, Microbes, Biological Methods, Detoxification

How to Cite:

Niamat, H. ., Tahir, A. ., Abdullah Zahid, M. ., Danyal Mustafa, M. ., & Ahmad, A. . (2022). The Efficacy of Microbes in the Detoxification of Industrial Effluent and Curbing of their Impact on Environment: Efficacy of Microbes in the Detoxification of Industrial Effluent. Pakistan Journal of Health Sciences, 3(04). https://doi.org/10.54393/pjhs.v3i04.112

***Corresponding Author:**

Humaira Niamat

Department of Biology, Lahore Garrison University, Pakistan

humairaniamat@lgu.edu.pk

Received Date: 13th September, 2022

Acceptance Date: 20th September, 2022

Published Date: 30th September, 2022

ABSTRACT

Microbes with their versatile abilities can potentially be used for the treatment of various industrial effluents; for removal or degradation of variety of harmful substances present inside them which would otherwise have severe detrimental impacts on terrestrial and aquatic environment, if discharged untreated. This article sums up the use of various microbes for treatment of several industrial effluents like industrial effluents from dyes, pesticide, plastic etc. The use of bacteria in dye industries can remove colors present in the wastewater, up to 100% in just 1 hour, if used as consortium. Plastic industrial effluents can also be treated by microbes, especially by forming biofilms. The article contains information about the selective use of these microbes coupled with different processes and highlights the best results achieved, without the addition of any chemical which might end up turning into a pollutant for the environment.

INTRODUCTION

There are various definitions to define pollution. Pollution can either be considered as the introduction of unwanted substances into the environment by man, in quantities enough to cause a disturbance to the environment. Industrial effluents coming from different industries such as textile, pesticide and plastic industries etc. contribute majorly to pollution considering their subtle effects on life related aspects such as behavior, reproduction/health and even survival of biotic communities. Organic pollutants can be removed using physical and chemical methods of industrial effluent treatment processes but the removal is at low level; these methods/processes are extremely selective to the range of pollutants removed and the expensiveness of these procedures is a difficult obstacle to climb. Pollution control is today's one of the primary concerns of the society but because of the economic on pollution control processes, relatively affordable methods having good efficiency have turned into a necessity. Nowadays, because of the increase in population and urbanization, the demand for resources is also increasing. To fulfil these increasing demands, industrial growth takes place which results into an increased generation of wastewater [1]. With the advancement in technology, various biotechnological approaches have been recommended to get over the limitations of physiochemical methods. These approaches involve the use of microorganisms for the treatment of different industry effluents e.g., textile dyes.

The Textile Industry

In many countries including China and South Africa estuaries, the textile sector plays a major role in the global economy and environmental pollution [2]. The textile dyes

DOI: https://doi.org/10.54393/pjhs.v3i04.112

are used in the textile sector which includes Azo dye – due to the affordability and simplicity of azo dyes, they are used in rubber, enamel, textile industries, etc. About 1 million tons of dyes are produced annually and 10% of them are released in environment as dyestuff waste. This wastewater produces brightly pigmented effluent having a large number of tenacious containments [3]. These dyes are poisonous teratogenic and malignant for both aquatic and human lives. They are non-biodegradable so some physiochemical reactions are employed but they treat the disposable issue and are non-environmentally friendly to human life.

Effect of Dyes on Aquatic and Terrestrial Environment:

About 71% of the surface on the globe is covered by water but still, one of the biggest problems faced by humanity is the need for pure drinking water. The quality of water is destroyed by the textile sector. And the requirement for pure water is increasing at a tremendous rate. The textile industry discharges off many treated and untreated effluents containing azo dyes and other organic pollutants. Both living organism and the aquatic environment is badly influenced by untreated wastewater [4]. The aquatic flora is also affected by the dyes which are poured into the water from the textile industry. The most problematic flow of dye is its ability to absorb the sunlight and prevent it from penetrating the photic zone of water by reflecting it. Many remarkable ecological effects are seen from this which includes altered aquatic conditions and a reduction in the rate of photosynthesis [5].

Biological Treatment

Dyes include the textile dyes, have been reported as a primary danger to the environment, because of their non-biodegradable nature and stable properties in water [6]. The extent of effectiveness of decolorization by microorganisms depends on how good the selected microorganisms adapt to the conditions and they perform their activity. Various microorganisms are found to be capable of degrading textile dyes. These include bacteria e.g., *Neisseria sp., Aeromonas sp., Bacillus sp.* and *Vibrio sp.*, yeast, fungi and algae [7]. Use of fungi for the treatment of textile industry effluent has some known disadvantages, including the requirement of low pH for the optimum activity of enzymes, and requirement of long hydraulic retention time for thorough decolorization. In recent time, the interest in bacteria having the potentiality to mineralize or degrade various textile dyes, has been increasing. Involvement of oxidoreductive enzymes e.g., azoreductase, laccases, lignin peroxidase, etc. have mainly been used in the degradation of azo dye (bacterial degradation)[8].

Bacterial Cultures for the degradation of dyes:

Additionally, 60-70% of azo dyes are toxic, carcinogenic, and have resistance to conventional treatment methodologies because of their resistance to physiochemical nature and non-biodegradable nature [9]. However, many bacterial species such as *klebsiella*, *pseudomonas*, *Bacillus*, *Rhodococcus*, *and Shigella.* which have the capability of azo dyes biodegradation [10]. Because of their ability of high specific growth rates and easy cultivation in comparison with other microorganisms; they are highly beneficial in dye degradation. The efficiency of bacterial *consortium* containing *pseudomonas aeruginosa* BCH and *Providencia sp*. SDS were compared with each other to degrade Red HE3B to individual strains [11]. It was concluded that consortium had greater decolorization and degradation as compared to individual bacterial strains. In 1 hour, 100% decolorization of 50mg/L of Red HE3B tools place by consortium metabolic activity.

Fungal Cultures for the degradation of dyes:

Fungi play a major role in the breakdown and mineralization of varying degrees of textile dyes through different fungal strains. Many enzymes such as manganese peroxidase, laccase, and lignin peroxidase, which are both intra-cellular and extra-cellular, increase metabolic activity and aid in the procedure of dye-containing wastewater. A mixture of pollutants from wastewater and the textile sector which are composed of polycyclic aromatic hydrocarbon are degraded by *Phanerochaete chrysosporium*. Congo Red with a decolorization efficiency of 97% was successfully biodegraded by *Aspergillus niger* showing that 27% of *Congo Red* could be removed by 1g of fresh biomass by process of biosorption. Whereas 70% of dye can be removed by biodegradation with the aid of a mixed reaction of enzymes such as manganese peroxide, lignin peroxide, and possibly deaminase [12]. Moreover, 70 – 80% of dye molecules can be removed by a fungal enzyme, Laccase.

The Pesticide Industry

Pesticides are a well-known source of improvement in the food crop productivity; by helping in controlling the pests. But this assistance does not come alone. The pesticides can not only cause pollution but can also become a part of the food chain, which in result could turn the drawbacks outweigh the advantages. Hence, the necessity of properly treating of pesticide mixed industrial wastewater before its release in water bodies is un-ignorable.

Adverse Effects:

The industrial wastewater coming from pesticides production units is enriched with both organic and inorganic compounds. This might seem like a typical characteristic but pesticide mixed wastewater is quite difficult to treat biologically, courtesy of the toxicity posed by pesticides to microbes. Apart from the toxicity, its recalcitrant characteristics, high chemical oxygen demand, high total suspended solids and highly acidic

DOI: https://doi.org/10.54393/pjhs.v3i04.112

conditions are the major challenges in treating the pesticide industrial wastewater [13]. Researches have linked exposure to pesticides for longer times to neurological disorders, reproductive complications, cancer, immunological, and pulmonary diseases citing their potential for teratogenicity, carcinogenicity and mutagenicity. Various types of pesticides are employed for the purpose of pest control. These include organochlorine (e.g., DDT), carbamates (e.g., carbaryl), organophosphates (e.g., malathion), and pyrethroids (e.g., pyrethrins). The nonbiodegradable and persistence nature make these chemicals highly toxic to the flora and fauna [14]. The conventional methods opted for treatment of pesticide mixed industrial wastewater include process such as chemical oxidation, Fenton oxidation, ozonation, photochemical degradation e.g., UV radiations, and membrane distillation etc. are used. But all these methods come with some limitations. Apart from that, these methods are expensive, difficult to carry out and require use of other chemical compounds, which might pollute the environment, even further. Microbial treatment methods, on the other hand, are free of these problems, relatively. The efficiency is better for a wide spectrum of substrates and the ease is noticeably greater if the processes are to be taken out *in situ*[15].

Microbial Treatment

Microorganisms such as bacteria, algae and fungi have been found useful in getting rid of the above discussed recalcitrant compounds. The way by which microbes eradicate these compounds, is by consuming them; metabolize them to use intermediates as a source of energy for processes like Krebs cycle. The strains which are able to do so have been isolated, screened and cultured, from various water bodies. For example, five bacterial genera were isolated from the Kor River in Iran, which were able to degrade an organochlorine endosulfan, which is effective against aphids, fruit-worms, moth larvae. The five genera were *Klebsiella*, *Acinetobacter*, *Alcaligenes*, *Flavobacterium*, and *Bacillus*. The production of metabolites such as endosulfan diol, endosulfan lactone, and endosulfan ether was also documented, but these metabolites were found to be of lesser toxicity than endosulfan itself [15]. Microbes of same ability can be used both in situ (composting and bio-stimulation etc.) and ex situ (bioreactors and bio filters etc.) for various pesticides. They can also be added as xenobiotic compounds to the site of treatment, if the efficiency of native microbes is not well reputed.

Bacterial Treatment

Various types of pesticides for example, organochlorines, which include Dichlorodiphenyltrichloroethane or DDT, are known to be degradable by different genera of bacteria. The degradation of pesticide residues mainly incorporates the metabolic processes in which microbes growing with the help of some growth substrate, are used to degrade the residues without any energy or food (nutrients) from the process. For instance, *Pseudomonas fluorescents* has been reported to degrade the organochlorine aldrin by 94.8% [16]. *Achromobacter xylosoxidans* strain CS5 has been reported to be able to utilize both the endosulfan and its sulfate (endosulfan sulfate) as an energy source, sulfur and a carbon source. This results in endosulfan's thorough mineralization via hydrolytic pathway [17]. *Dehalococcoides sp.* has been observed to dechlorinate Hexachlorobenzene, anaerobically, the product of the cbrA gene is reported to be degraded by the enzyme, trichlorobenzene reductive dehalogenase. *P. putida* MAS-1 is accounted for more than 90% degradation of chlorpyrifos, in minimal salt concentration [18]. Five bacterial species, isolated from cockroaches residing in pesticide contaminated areas, were reported to degrade endosulfan with following efficiencies [19].

Bacterial Species	Endosulfan Bioremediation Efficiency
Pseudomonas aeruginosa	88.5%
Stenotrophomonas maltophilia	85.5%
Acinetobacter l	80.2%
woffiiBacillus atrophaeus	64.4%
Citrobacter amalonaticus	56.7%

Table 1: Bacterial species and their efficiencies in degrading endosulfan

Fungal Treatment

Fungi are likewise capable of treating and degrading pesticides. A study was conducted by Xiao et al. to evaluate the species of fungi which were competent to degrade the organochlorine heptachlor and its epoxide. The three fungal species, *P. brevisporam*, *P. acanthocystis* and *P. tremellosa*, after a two weeks' incubation period, were noted to have 74%, 90% and 71% remediation efficiency of heptachlor, respectively. The metabolism of heptachlor yielded 1-hydroxy-2, 3- epoxy-chlordene, heptachlor epoxide, and 1-hydroxychlordene, and after two weeks 25%, 16%, 22%, and 16% removal of heptachlor epoxide was observed by *P. aurea*, *P. acanthocystis*, *P. lindtneri*, and *P. brevispora*, respectively [20]. Three fungal species, *Spingobium indicum*, *Spingobium francense*, and *Spingobium japonicum*, all possessing the lin gene were found to be capable of taking up and metabolizing the agricultural insecticide hexachlorocyclohexane. A yeast, *Rhodotorula mucilaginosa* strain IM-2 has been reported for the remediation of two neonicotinoid insecticides, acetamiprid and thiacloprid [21]. Similarly, degradation of endosulfan and endosulfan sulfate through the hydrolytic pathways has been observed with white rot fungus *Trametes hirsute*. Degradations of fungicide

DOI: https://doi.org/10.54393/pjhs.v3i04.112

difenoconazole, herbicide pendimethalin, and the algicide/microbicide terbuthylazine have been reported by the use *Fusarium oxysporum*, *Penicillium brevicompactum*, *Lentinula edodes*, *Lecanicillium saksenae* (99.5% removal of pendimethalin), and *Aspergillus oryzae* (maximum 80% removal of terbuthylazine), and were shown to be able to [22].

The Plastic Industry

From distinct hydrocarbons and petroleum by-products, high molecular weight natural polymers are obtained. These polymers are referred to as plastic. For example, Polypropylene (PP), Polyester (PET), Polyethylene (PE), Polyvinylchloride (PVC), Polystyrene (PS), and the High-Density Polyethylene (HDPE). Plastics, the basis of many factories, are used to make various products i.e., toy materials, sanitary wares, tiles, plastic bottles, wires, bulbs, and various home items. They are also utilized in covering/packaging food products, medicines, detergents, and cosmetics [23]. Plastic is inert however, the wastewater effluent discharged from the plastic industry directly into the aquatic environment arises a major problem. These effluent results in unpleasant odor emissions, and change in groundwater quality, poisoning the land, which somehow influences the aquatic life as well as the health of neighborhood inhabitants[24].

Detrimental Impact on the Environment:

The effluent of the plastic industry tends to absorb organic pollutants that are being discharged into water bodies. Harmful chemicals coexisting in the depth of water bodies with plastic scrap include polychlorinated biphenyls (PCBs), and natural pesticides i.e., bisphenol A (BPA) etc. These harmful agents tend to cause health issues i.e., cancer of breast and arthritis, damage to the hypothalamus of the brain, and disturbs neurological activities it also results in lower methylation of deoxyribonucleic acid and lastly led to diabetes issues. Bisphenol A utilized in plastic production when consumed accidentally within the smaller percentage can cause hormonal imbalance and mutagenic issues in living beings and at a percentage up to 0.4 milli molars, it can result in minimal toxicity in aquatic species [25]. Besides from effluents the degradation of plastic generates particles having a size greater than 5mm known as micro plastics (MP) which led to potential Eco toxicological effects [26]. MPs are drained out with industrial waste in aquatic bodies and become harmful to the environment as it is often considered food by marine animals. In the stomach of these species, the ingested plastic particles endure and lead to a lessening natural capacity of gastric enzyme release, intestinal obstruction, reduced hunger, breeding issues, and lessening of various hormonal levels[27].

Microbial Remedy to Degrade Pollutants

Various microbes also used to be extremely helpful in degrading the plastic particles drained in the aquatic environment by plastic industries. However, chemical treatment, coagulation, flocculation, and incineration, are not favored because of some limitation that leads to causing more harm to our environment. Biological remedies have significant importance as they are eco-friendly such as using phytoremediation biotechnology which circumscribes microbe and plant-based degradation, and has given promising results[28].

Bioremediation of Bisphenol A (BPA)

The plant endophytic-bacterium *P. dispersa* and its available host *D. sanderiana* had been verified to treat plastic effluent that contains bisphenol A. Moreover, a strain of bacterial specie known as, *Bacillus cereus NI*, from the wastewater has the potential to terminate BPA in a high total dissolved solid and alkaline environment. The outcome states that a strain that is inoculated before use has a positive result and appears to remove the highest BPA percentage up to 89.54 % in contrast to that strain that was not inoculated, after 5 days of treatment. Each remedy was carried out in the presence of natural lightning. In this event, it is observed that loss of BPA was influenced by temperature and light use these parameters increased the degradation also speeds up in the presence of sterile water [28]. Also, the pH, salinity, TDS, COD, and BOD tend to decrease by a greater amount after the whole experimental time. Specifically, BOD tends to decrease significantly due to the action of the plants and microbe.

Usage of Biofilms to Degrade Micro plastics:

Biofilms are of great advantage in capturing and degrading micro plastics (MPs) found in aquatic ecosystems. It works by creating an interaction between microbes and microplastics thus reducing the toxicity of chemicals that are associated with MPs. Members of marine *Erythrobacteraceae* have been demonstrated to colonize both microplastics (MPs). Biofilms on the surface of MPs attract other MPs from the environment, and in addition to that, it generates an odor of DMS, which tends to attract specific groups of Arthropods known as *copepods* that help in degrade MPs by ingesting them [29]. There are other fungal and bacterial species mentioned in the table below that contribute to the degradation of those plastics that can absorb harmful chemicals from the surroundings and are being drained out in nearby water systems[30].

DOI: https://doi.org/10.54393/pjhs.v3i04.112

Plastic Type	Microorganism Used	Result	Ref.
Polyester polyurethane (PUR)	Lasiodiplodia spp. (strain: E2611A), Pleosporales spp. (strain: E2812A), Bionectria spp. (strain: E2910B), and three other members of same genus.	By using FTIR all of them cleared PUR by significant amount but most active strain that out perfor is Lasiodiplodia spp.	[31]
LD polyethylene film	Aspergillus Versicolor & Aspergillus spp. (Both were isolated from Sea water)	Microbes degraded LDPE into max CO2 by biodegradation.	[32]
Polyethylene products	Bacillus subtilis, Bacillus amylolyticus, Arthobacter defluvii	Per month by degradation the weight loss is up to 30% in liquid culture.	[33]

Table 2: Microbes used in the degradation of plastic

CONCLUSIONS

Microorganisms are capable of treating various industrial effluents. Using the discussed types of bacteria, fungi, and algae to degrade the waste products of an industry is a better way than using chemicals. Use of microbes is not only an inexpensive but also an efficient method of curbing the detrimental effects of industrial effluents when compared to both mechanical/physical and chemical treatments. The microbes can help protect the environment particularly the water bodies which are the primary victims of the pollution caused by industrial wastes. The conditions required by the microorganisms, are relatively easy to establish/attain and are easy to work with.

Conflicts of Interest

The authors declare no conflict of interest.

Source of Funding

The author(s) received no financial support for the research, authorship and/or publication of this article

REFERENCES

[1] Baig N, Ihsanullah, Sajid M, Saleh TA. Graphene-based adsorbents for the removal of toxic organic pollutants: A review. Journal of Environmental Management. 2019 Aug; 244:370-382. doi: 10.1016/j.jenvman.2019.05.047.

[2] Olisah C, Adams JB, Rubidge G. The state of persistent organic pollutants in South African estuaries: A review of environmental exposure and sources. Ecotoxicology and Environmental Safety. 2021 Aug; 219:112316. doi.10.1016/j. ecoenv. 2021. 112316

[3] Ali SS, Al-Tohamy R, Sun J. Performance of Meyerozyma caribbica as a novel manganese peroxidase-producing yeast inhabiting wood-feeding termite gut symbionts for azo dye decolorization and detoxification. Science of The Total Environment. 2022 Feb; 806:150665. doi.10.1016/j.scitotenv.2021.150665

[4] Mudhoo A, Ramasamy DL, Bhatnagar A, Usman M, Sillanpää M. An analysis of the versatility and effectiveness of composts for sequestering heavy metal ions, dyes and xenobiotic from soils and aqueous milieus. Ecotoxicology and Environmental Safety. 2020 Jul; 197:110587. doi: 10.1016/j.ecoenv. 2020.110587.

[5] Chen G, An X, Li H, Lai F, Yuan E, Xia X, et al. Detoxification of azo dye Direct Black G by thermophilic Anoxybacillus sp. PDR2 and its application potential in bioremediation. Ecotoxicology and Environmental Safety. 2021 May; 214:112084. doi: 10.1016/j.ecoenv.2021.112084.

[6] Zhang X, Wang J, Dong XX, Lv YK. Functionalized metal-organic frameworks for photocatalytic degradation of organic pollutants in environment. Chemosphere. 2020 Mar; 242:125144. doi: 10.1016/j.chemosphere.2019.125144.

[7] Karim ME, Dhar K, Hossain MT. Decolorization of Textile Reactive Dyes by Bacterial Monoculture and Consortium Screened from Textile Dyeing Effluent. Journal of Genetic Engineering and Biotechnology. 2018 Dec; 16(2):375-380. doi: 10.1016/j.jgeb. 2018.02.005.

[8] Krishnaswamy VG. Role of Enzymes from Microbes in the Treatment of Recalcitrant from Industries. Research Advancements in Pharmaceutical, Nutritional, and Industrial Enzymology. 2018:395-420.

[9] Rawat D, Sharma RS, Karmakar S, Arora LS, Mishra V. Ecotoxic potential of a presumably non-toxic azo dye. Ecotoxicology and Environmental Safety. 2018 Feb; 148:528-537. doi: 10.1016/j.ecoenv.2017.10.049.

[10] Chen YG, He XL, Huang JH, Luo R, Ge HZ, Wołowicz A, et al. Impacts of heavy metals and medicinal crops on ecological systems, environmental pollution, cultivation, and production processes in China. Ecotoxicology and Environmental Safety. 2021 Aug; 219:112336. doi: 10.1016/j.ecoenv.2021.112336.

[11] Phugare SS, Kalyani DC, Patil AV, Jadhav JP. Textile dye degradation by bacterial consortium and subsequent toxicological analysis of dye and dye metabolites using cytotoxicity, genotoxicity and oxidative stress studies. Journal of Hazardous Materials. 2011 Feb; 186(1):713-23. doi: 10.1016/j.jhazmat.2010.11.049.

DOI: https://doi.org/10.54393/pjhs.v3i04.112

[12] Asses N, Ayed L, Hkiri N, Hamdi M. Congo Red Decolorization and Detoxification by Aspergillus niger: Removal Mechanisms and Dye Degradation Pathway. Biomed Research International. 2018 Aug; 2018:3049686. doi: 10.1155/2018/3049686.
[13] Wang S, Kirillova K, Lehto X. Travelers' food experience sharing on social network sites. Journal of Travel & Tourism Marketing. 2017 Jun; 34(5):680-93.
[14] Roy A, Roy M, Alghamdi S, Dablool AS, Almakki AA, Ali IH, et al. Role of Microbes and Nanomaterials in the Removal of Pesticides from Wastewater. International Journal of Photoenergy. 2022 Jun; 2022.
[15] Kafilzadeh F, Ebrahimnezhad M, Tahery Y. Isolation and identification of endosulfan-degrading bacteria and evaluation of their bioremediation in kor river, iran. Osong Public Health and Research Perspectives. 2015 Feb; 6(1):39-46. doi: 10.1016/j.phrp.2014.12.003.
[16] Bisht J, Harsh NS, Palni LM, Agnihotri V, Kumar A. Biodegradation of chlorinated organic pesticids endosulfan and chlorpyrifos in soil extract broth using fungi. Remediation. 2019. Jundishapur journal of microbiology. 2020.
[17] Odukkathil G and Vasudevan N. Toxicity and bioremediation of pesticides in agricultural soil. Reviews in Environmental Science and Bio/Technology. 2013 Dec; 12(4):421-44.
[18] Ajaz M, Rasool SA, khan Sherwani S, Ali TA. High profile chlorpyrifos degrading Pseudomonas putida MAS-1 from indigenous soil: gas chromatographic analysis and molecular characterization. International Journal of Basic Medical Sciences and Pharmacy(IJBMSP). 2012 Dec; 2(2).
[19] Ozdal M, Ozdal OG, Alguri OF. Isolation and Characterization of α-Endosulfan Degrading Bacteria from the Microflora of Cockroaches. Polish Journal of Microbiology. 2016; 65(1):63-8. doi: 10.5604/17331331.1197325.
[20] Xiao P, Mori T, Kamei I, Kondo R. Metabolism of organochlorine pesticide heptachlor and its metabolite heptachlor epoxide by white rot fungi, belonging to genus Phlebia. FEMS Microbiology Letters. 2011 Jan; 314(2):140-6. doi: 10.1111/j.1574-6968.2010.02152. x.
[21] Dai YJ, Ji WW, Chen T, Zhang WJ, Liu ZH, Ge F, et al. Metabolism of the Neonicotinoid insecticides acetamiprid and thiacloprid by the yeast Rhodotorula mucilaginosa strain IM-2. Journal of Agricultural and Food Chemistry. 2010 Feb; 58(4):2419-25. doi: 10.1021/jf903787s.
[22] Pinto AP, Serrano C, Pires T, Mestrinho E, Dias L, Teixeira DM, et al. Degradation of terbuthylazine, difenoconazole and pendimethalin pesticides by selected fungi cultures. Science of the Total Environment. 2012 Oct; 435-436:402-10. doi: 10.1016/j.scitotenv.2012.07.027.
[23] Piergiovanni L and Limbo S. Introduction to food packaging materials. In Food Packaging Materials 2016; 1-3. Springer, Cham.
[24] Hardesty BD, Good TP, Wilcox C. Novel methods, new results and science-based solutions to tackle marine debris impacts on wildlife. Ocean & Coastal Management. 2015 Oct; 115:4-9. doi.10.1016/j.ocecoaman.2015.04.004
[25] Zhang W, Yin K, Chen L. Bacteria-mediated bisphenol A degradation. Applied Microbiology and Biotechnology. 2013 Jul; 97(13):5681-9. doi: 10.1007/s00253-013-4949-z.
[26] Guo JJ, Huang XP, Xiang L, Wang YZ, Li YW, Li H, et al. Source, migration and toxicology of microplastics in soil. Environment international. 2020 Apr; 137:105263. doi.10.1016/j.envint.2019.105263
[27] Wang F, Wang B, Duan L, Zhang Y, Zhou Y, Sui Q, et al. Occurrence and distribution of microplastics in domestic, industrial, agricultural and aquacultural wastewater sources: A case study in Changzhou, China. Water Research. 2020 Sep; 182:115956. doi.10.1016/j.watres.2020.115956
[28] Suyamud B, Thiravetyan P, Gadd GM, Panyapinyopol B, Inthorn D. Bisphenol A removal from a plastic industry wastewater by Dracaena sanderiana endophytic bacteria and Bacillus cereus NI. International journal of phytoremediation. 2020 Jan; 22(2):167-75. doi.10.1080/15226514.2019.1652563
[29] Debroy A, George N, Mukherjee G. Role of biofilms in the degradation of microplastics in aquatic environments. Journal of Chemical Technology & Biotechnology. 2021 Nov; doi.10.1002/jctb.6978
[30] Kale SK, Deshmukh AG, Dudhare MS, Patil VB. Microbial degradation of plastic: a review. Journal of Biochemical Technology. 2015 Dec; 6(2):952-61.
[31] Russell JR, Huang J, Anand P, Kucera K, Sandoval AG, Dantzler KW, et al. Biodegradation of polyester polyurethane by endophytic fungi. Applied and environmental microbiology. 2011 Sep; 77(17):6076-84. doi.10.1128/AEM.00521-11
[32] Sindujaa P, Padmapriya M, Pramila R, Ramesh KV. Bio-degradation of low density polyethylene (LDPE) by fungi isolated from marine water. Research Journal of Biological Sciences. 2011; 6(4):141-5. Doi: 10.5897/Ajmr11.670
[33] Thakur P. Screening of plastic degrading bacteria from dumped soil area(Doctoral dissertation). 2012