Biodegradation and impact of polycyclic aromatic hydrocarbons in the environment:

A Concise Review

Abstract

Polycyclic aromatic hydrocarbons are chemical substances that are produced from natural sources such as volcanic eruptions and from anthropogenic sources such as incomplete combustion of fuels such as coal, oil, gas and waste materials. They are mostly implicated among numerous toxic compounds in the ecological system. Exposure of such organic pollutants in the environment endangers animals, plants, microbial, soil, and aquatic lives. Human beings are at a high risk of developing cancers due to pollutants exposure. The existence of such pollutants in the surroundings endangers microbial life by affecting cell growth, shape and metabolic process, alters genetic composition and membranes of microbial cells. The major routes of microbial degradation of organic pollutants are via growth and co-metabolism. The processes enable microorganisms to metabolize toxic compounds in the cells milieu, so as to transform contaminants into harmless forms such as carbon dioxide and water. Bioremediation remains the safest and eco-friendly means of returning toxic environment to a harmless state. The present study aims to present an overview of biodegradation of polycyclic aromatic hydrocarbons in the natural world and the adverse effect of the compounds in the environment. .

Keywords: Biodegradation, bioremediation, environmental contaminants, hydrocarbons, microorganism, pollutants degradation

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Introduction

The environment is witnessing significant pollution arising due to industrialization and other activities of man. Polycyclic aromatic hydrocarbons are chemical substances that are produced from natural sources such as volcanic eruptions and from anthropogenic sources such as partial combustion of fuels such as coal, oil, gas and waste materials. The natural sources of contamination and entry of polycyclic aromatic hydrocarbons in the environment are usually derived from natural sources such as volcanic eruptions and hydrothermal processes [1]. Generally, anthropogenic sources of PAHs contamination are petrogenic and pyrolytic. Petrogenic PAHs are usually derived from crude and refined petroleum, and are usually introduced to the aquatic and soil environment through accidental oil spills, pipeline blowouts, improper drainage and discharges from vehicles. Pyrolytic sources are due to incomplete combustion of fuels such as oil, gas and biomass [2]. Polycyclic aromatic hydrocarbons (PAHs) are one of the most extensively disseminated toxic compounds in our surroundings due to their introduction from many anthropogenic sources. Significant proportions of PAHs that are emitted globally are due to human activities such as cooking with firewood, and farming activities such as burning of agricultural wastes. PAHs can as well emanate from other anthropogenic sources such as during manufacturing of products by industries, burning of diesel engines for power generations and combustion of fuels by automobiles. When released in the surroundings, they portend great ecological and health concern. Choi *et al*., (2020) [3] reported that PAHs are one of the main elements of crude oil. Annually, large quantities of petroleum products are discharged into the soil and water bodies either accidentally or improperly due to mining, transportation, leakages from pipelines and blow out.

Based on structure, PAHs are compounds with two or more fused benzene rings in their structural configurations. They are made up of complex aromatic rings in linear, angular, or cluster arrangements [4]. This legacy compound contaminates the environment and has been considered as emerging pollutant [5]. The contaminants at increased concentrations in the environment become toxic to aquatic, plants, animals, microbial and other life forms. Human beings are vulnerable to carcinogenic, teratogenic, and mutagenic hazards when exposed to PAHs [6]. There are over 100 PAHs distributed in nature that usually occur as a complex mixture and not as a single compound [7]. Mixtures of PAHs can be found in incomplete burning of products such as black soot. PAHs can also be manufactured as a single compound for use in research. When found as unadulterated chemicals, they are usually colorless, white, or pale yellow-green solids. They also have a light and pleasing odor.

PAHs are ubiquitous contaminants in nature. Lim *et al*., (2021) [8] noted that they can be found as pollutants in air, sediments, soil and aquatic environments as well as surface and underground waters. The prototypic PAHs such as naphthalene, anthracene and phenathrene usually serve as indicator compounds for the presence of PAHs in the environment. PAHs in the environment are generally extracted into an organic solvent prior to separation using analytical equipments [1]. Researchers have used numerous analytical instruments/methods in the extraction of PAHs such as gas chromatography (GC), high performance liquid chromatography (HPTLC), Fourier transform infrared spectroscopy (FTIR), supercritical carbon dioxide solvent extraction [9], Tenax extraction [10], and solid phase nonextraction-gas chromatography/mass spectrometry [11].

There are reports of some compounds of PAHs such as anthracene used for the production of the chemotherapeutic agent called Amsarcine [12]. The authors equally noted that Acenaphthene is used as a raw material (dye intermediate) in the production of plastics and as insecticides and fungicides. Fluoranthrene also has applications as a coating material to preserve the internal layer of steel and ductile-iron drinking water pipes and storage tanks [13]. Organisms are exposed to compounds such as Benzol(a)pyrene (Bap) due to release from industries and automobiles, hazardous wastes dump, biomass burning, waste burning, municipal incinerators, volcanic eruptions and absorption from smoked food. The presence of the various forms of PAHs in the environment causes harmful effects on microorganisms and other life forms. The intervention of degrading microbes unburdens toxicity rates in environment, decontaminates the environment, and makes them beneficial for agricultural purposes. Microorganisms as silent operators in the environment have the responsibility to ensure that our surroundings are returned to normal despite the challenges. Microorganisms have developed machineries to surmount the harmful effects due to contaminants. The metabolic expertise of microbes helps them in degradation of toxic contaminants. Eze and Orjiakor (2020) [14] noted that the distributions of hydrocarbonclastic microorganisms in the environment are beneficial in hydrocarbon removal in the environment.

Toxicity

There are over 100 different PAHs compounds in nature and 16 of these PAHs have been listed as environmental pollutants of main concern as a result of their toxicity, persistent, mutagenic and carcinogenic characteristics. PAHs are characterized by their electrochemical stability, persistency, structural angularity, hydrophobicity, volatility, carcinogenic, and recalcitrance toward biodegradation [15]. The extent of toxicity of PAHs depends on the molecular weight [16]. The low molecular weights (LMW) PAHs are described as acutely toxic and contain two or three aromatic rings. Meanwhile, high molecular weights (HMW) PAHs are regarded as genotoxic and contain four or more rings [16, 17]. The high molecular weight (HMW) PAHs do not dissolve easily in water, they are less explosive and more lipophilic than the low molecular weight (LMW) PAHs [18]. The observed relationship between PAHs and the rising quantity of benzene rings is consistent with the outcome of some findings linking biodegradation time and PAH molecule size [19].

The main routes of PAHs exposure in humans is from breathing ambient and indoor air, smoking, and consumption of meals containing PAHs. Humans may be exposed to PAHs in their work places with observable symptoms such as irritation of the eyes, confusion, vomiting and nausea. Ingestion of high concentrations of Napthalene can cause haemolysis [20]. Additionally, there are numerous risks associated with exposure to polycyclic aromatic hydrocarbon concentrations in humans such as life time cancer risk, respiratory infections, coughing, impaired lung function, cardiovascular disease, eye irritation, stroke, and death [21]. Investigations by Gourdazi *et al*., (2020) [22] showed that air around industrial areas recorded higher levels of PAHs compared to the air surrounding residential homes. Therefore, individuals living close to industrial zones are likely to be exposed to higher concentrations of PAHs. Factors that could determine the effect of PAHs on humans include; concentrations of PAHs, length and route of exposures, toxicity of PAHs, pre-existing health conditions and age of the exposed individuals.

Effects of PAHs on microorganisms

As noted earlier, microorganisms can be exposed to PAHs due to emissions from industries and automobiles, hazardous wastes dump, incinerations, biomass burning, waste burning, volcanic eruptions and absorption from smoked food. The pollutants can enter microbial system through absorption, respiration or by contact. There are reports of about fifty-four PAHs that were observed at various hazardous waste sites by the United States department of health and human services. Mumtaz and George (1995) [7] reported that concentrations of some indicator PAHs in the atmosphere are about 0.02-1.2 nanograms per cubic in rural areas and 0.15-19.3 ng/m^3 in urban areas. The authors equally reported some concentrations of PAHs in potable water range from 4 to 24 nanograms per liter. The observed report shows that the developed cities would have higher concentrations of PAHs compared to the rural communities.

Therefore, microorganisms could be exposed to greater concentrations of PAHs in regions with increased concentrations of PAHs. The occurrence of contaminants in high concentrations creates much danger to the microbial cells, including the ability of bacteria to attack pollutants. They can upset the microbial populations, either by escalating or diminishing the mass of certain bacterial or fungal populations based on the character of the contaminants [23]. The existence of toxic metals in the ecological system endangers microbial life by affecting cell growth and shape, metabolic processes, alters genetic composition and membranes of microbial cells. Additionally, Eze *et al*., (2020b) [24] reported that crude oil pollution inhibited bacterial and fungal counts on the soil and aquatic environments. The authors equally reported reductions in soil nutrients as the level of contamination by crude oil increased. Alimba and Faggio (2019) [25] noted that assimilation of contaminants by microorganisms can hinder metabolism and reproductive ability. The presence of contaminants in microorganisms interrupts physiological activities, energy storage, metabolism and survival of microorganisms. Environmental challenges such as the presence of contaminants can cause stress in microorganisms. Numerous environmental stress conditions that could be experienced by microbes include changes in concentration of toxins, carbon source, amino acid limitations, heat shock, acid shock as well as starvations from nutrients such as carbon, nitrogen, and phosphate. In order to stay alive and energetic in the presence of stress, microbes develop physiological adaptation mechanisms [26].

Environmental fate of PAHs

The tendency of PAHs to resist biodegradation, with affinity to bioaccumulate and their deleterious effect on microorganisms is a significant concern. Bacteria have been found as the principal microorganisms involved in the detoxification of toxic compounds. The supply of vastly concentrated and specialized populations of microorganisms improves the ability and speed at which microbial populations degrade and convert toxic compounds [27]. Additionally, the addition of nutrients (biostimulation) that can stimulate autochthonous microorganisms in the degradation of pollutants is an effective means of detoxifying contaminants. Other environmental factors that could affect degradation of contaminants include oxygen, pH, temperature, moisture content, microbial population and chemical structure of compounds. Kaiser (2022) [28] stated that microorganisms have the ability to acclimatize to the presence of contaminants found around their system through the process of horizontal gene transfer, so as to utilize such contaminants as nutritional source of carbon and nitrogen. The horizontal gene transfer is critical in the development of bacteria that can mineralize legacy contaminants such as polycyclic aromatic hydrocarbons [29]. Toxic compounds readily undergo bioconversion into less toxic compounds in natural ecosystem. However, processes involving incomplete biotransformation of complex molecules still persist. Some of these compounds are converted into intermediates that are exceedingly recalcitrant to microbial enzymes, thereby making detoxification difficult. Rohini *et al.,* (2015) [30] enumerated reasons for the high resistant nature of some compounds in the ecosystem as follows:

1. The inability of biotransforming microorganisms to recognize the compounds as the substrate.
2. They are remarkably stable in ecosystem.
3. They possess large molecular weight which resists entry to microbial cells.
4. Less solubility in water.
5. They have high toxicity and affinity to release toxic products due to microbial actions.

However, the length of time each contaminant persists in the environment varies. It is a unique characteristic of contaminants to possess molecules of unusual elements, groupings and bond as compared biological standards [31]. The unique features make recognition by naturally occurring microorganisms challenging. It is noteworthy that toxic compounds do not enter the common metabolic pathway of microorganisms easily [32]. PAHs are less soluble in water and can highly adsorb solid particles; this quality makes them to last long in the environment prior to biodegradation. Pannu *et al*., (2003) [33] reported that low molecular weights PAHs are unstable and highly soluble in water and as such highly disposed to microbial utilization.

Transformation of PAHs can take place through processes such as adsorption, volatilization, photolysis, and chemical oxidation. However, the use of microorganisms for the conversion of contaminants remains the most ecologically sound means for the neutralization process of PAHs contaminated sites. There are two major pathways that could be effectively utilized by microorganisms in the degradation of PAHs via growth and co-metabolism. The growth pathway primarily involves the utilization of organic pollutants as a sole source of carbon and energy. Fritsche and Hofritcher (2008) [34] noted that this strategy could bring about mineralization of organic pollutants. Meanwhile, co-metabolism is a means of transformation of organic pollutants by microorganisms without nutritional benefit in the presence of a growth substrate. This mechanism involves microorganisms growing on a particular substrate gratuitously oxidize a second substrate (co-substrate). Microorganisms do not assimilate the co-substrate, but the product may be available as substrate for other microorganisms of a mixed culture. When pure culture is involved, co-metabolism is a transformation without benefit to the organism. Meanwhile, this initial co-metabolic transformation may pave way for subsequent attack by another organism in the environment [35]. It is the basis of biotransformation used to convert a substance to a chemically modified form. Zhong *et al*., (2007) [36] stated that co-metabolism is an essential means of transforming non-substrate PAHs in the presence of growth substrate to enlarge the range and extent of PAHs degradation.

Bacterial degradation of PAHs

The mineralization of hydrocarbons is essentially a development that relies heavily on the presence of oxygen. Most frequent aerobic degrading microbes are established in bacterial and fungal populations. The primary oxidation of benzene ring by the action of dioxygenase enzymes to form cis-dihydrodiols is the most important procedure for the aerobic bacterial metabolism [37]. The cleavage of the aromatic ring occurs at the rate limiting step as the first enzymatic process during aerobic PAH degradation. Elliot *et al*; (2010) [38] reported that an essential system for the aerobic bacterial conversion of naphthalene and PAHs is through oxidative action of the naphthalene dioxygenase enzyme complex which initiates molecular oxygen.

This enzyme complex explicitly integrates an oxygen atom to the two carbon atoms that were formerly sharing a bond, forming a cis-dihydrodiol (Fig. 1). The intermediates further experience ortho or metacleavage giving rise to Cis-muconic acid or 2-hydromuconic semialdehyde, respectively [39]. The ring cleavage give rise to the formation of sucinic, fumaric, pyruvic, and acetic acids and aldehydes (Fig. 1), these products are precursors for the synthesis of cellular constituents and energy by the microorganisms [40]. Also, there are reports about mobile genetic elements (MGEs) like plasmids and transposon being useful in the mineralization of organic contaminants such as PAHs [4].

Bacterial populations such as *Sphingomonas*, *Pseudomonas* and *Mycobacterium* were reported as the main microorganisms in PAHs mineralization in soil [41]. *Pseudomonas* strains such as *Pseudomonas sacharophila* P 15, isolated from creosote-polluted soil were observed to efficiently enhance the removal rates of fluoranthene, pyrene, benz[a]anthracene, chrysene and benzo[a]pyrene when salicylate was used as inducer of PAH dioxygenase activity [19, 39, 42].

Gupta and Pathak (2020) [43] also identified the potentials of *Burkholderia* in degrading 2- or 3-ring PAH such as naphthalene and anthracene, while noting *Mycobacterium* greater efficiency in degrading complex PAHs such as fluoranthene, benzo-alpha-pyrene. Kanaly and Harayama (2020) [19] reported on the ability of *Rhodococcus* sp strain UW1 isolated from hydrocarbon-polluted soil. The authors noted their potentials to metabolize Pyrene and Chyrsene as sole sources of carbon and energy. Among PAHs degrading bacteria, genus bacteria *Rhodococci* are very distinctive due to their enormous catabolic versatility [4].

Fungal degradation of PAHs

Fungal utilization of PAHs are facilitated by the non-ligninolytic and ligninolytic fungi (the white rot fungi), Bamforth and Singleton (2005). The non ligninolytic fungi uses cytochrome P450 monoxygenase enzyme which catalyze the oxidation of PAHs to arene oxides, the primary product of PAHs metabolic processes. The arene oxide intermediate is carcinogenic and can further be metabolized by epoxide hydrolase to form a trans-dihydrodiol Fig 1. However, the transdihydrodiol product cannot be used in organisms that use the cytochrome P-450 system as energy source [44, 39]. The cytrochrome is an essential enzyme in contaminants metabolism and are useful in the pharmaceutical industry due to their effectiveness in breakdown of medications.

The ligninolytic fungi popularly called white rot in wood. Their ability to absolutely convert PAHs to carbon dioxide and water has made them efficient and extensively used in bioremediation [45]. The ligninolytic fungi has the ability to produce enzymes such as lignin peroxidase (LiP), manganese peroxide (MnP), versatile peroxidise (VP) and laccases (LAC) to degrade lignin in wood [46]. LiP was said to play significant role for the initial steps in benzo[a]pyrene metabolism by *P.chysporium* [44]. The enzyme activity of LiP can be evaluated by the oxidation of veratryl alcohol (VA) which is preferred LiP substrate, to veratradehyde by the increase in absorbance at 310 nm [47].

The degradation of PAH by MnP was originally studied in *P.chrysporium* and expressed as a lipid peroxidation dependent process [48]. There are also reports that PAH degradation by some MnPs also takes place directly [44]. The efficiency of MnP in PAH degradation was shown by Acevedo *et al*., (2010) [49] who reported that MnP produced by *Anthracophyllum discolor* was able to degrade pyrene (>86%) and anthracene (>65%) alone or in mixture. Meanwhile, the authors noted lesser success in degrading flouranthene (<15.2 %) and phenanthrene (<8.6%).

Meanwhile, reports are sparse on versatile peroxidase production during PAH degradation by white-rot fungi [50]. Pozdnyakova, (2012) [44], noted that PAHs oxidation by versatile peroxidase from *Bjerkandera adusta* in the presence and absence of Manganous ions.

PAH oxidations by purified fungal laccases have been studied with laccase from *Trametes versicolor, Pleurotus ostreatus, Coriolus hirsutus*, and *Coriolopsis gallica* [51]. There was simultaneous reduction of one dioxygen molecule to two molecules of water and oxidizing aromatic substrates by the Laccases [12, 52] Brazkova and Krastanov, 2013). The authors equally investigated the efficacy of laccase, produced by *Trametes versicolor* in the removal of aromatic compounds. The removal rate of acenaphthylene was found to have the highest removal rate of 37% , the anthracene and benzo(a)pyrene were 18 and 19%, respectively, and the removal rate for other PAHs investigated were found to be less than 10%. The addition of 1-hydroxybenzotriazole (HBT) to the reaction mixture induced the oxidation of PAHs resulting in virtually total removal of acenaphthylene, acenaphthene, fluorene, anthracene, benzo(a)pyrene, and perylene.

Pozdnyakova, (2012) [44], reported that LAC from *Coriolopsis gallica* successfully oxidized flouranthene (75%) as well as its polycyclic heterocyclic analogs involving carbazole (100% loss), n-ethylcarbozole, (100%), and dibenothiophene (60%) in the presence of 1-hydroxybenzotriazole (HBT) and 2,2'-azinobis(3-ethylbenzthiazoline-6-sulfonic acid) as free radical mediators.

Ligninolytic fungi such as *Phanerochaete chrysoporium* and *Pleurotus ostreatus* can secrete both ligninolytic and non-ligninolytic type of enzymes, but uncertainties surround the extent each enzymes could take part in the degradation of PAHs [51]. Brown rot fungi are another type of ligninolytic fungi that essentially produces hydrogen peroxide for the degradation of hemicelluloses and cellulose. Brown rot fungi such as *Laetiporus sulphureus* and *Flammulina velutipes* can metabolize PAHs like phenanthrene, flouranthene, and fluorine [46,53].

Microalgal degradation of PAHs

Microalgae are photosynthetic autotrophs which are microscopic and form the major primary producers in the aquatic environment with applications in wastewater treatment, food and cosmetic industries, and bioenergy production. Its application for wastewater treatment has been subject of study for about a decade ago [54], and some strains have been identified with the potentials to biodegrade PAHs in aquatic environments [4, 55]. The potential of bio removal of fluorene by *Chlorella vulgaris* was studied in BG 11 medium supplemented with different concentrations of fluorine under phototrophic condition [55]. According to the report, some biodegradable byproducts such as N-Hydroxymethylcarbazol, Dibutyl phthalate, Hexadecanoic acid, ethyl ester, and 1, 2-Benzenedicarboxylic acid, dioctyl ester was identified from the culture medium [55], which formed the proposed degradation pathway in fig. 2. The fluorine degradation pathway by *C. vulgaris* started with the opening of the aromatic ring possibly by the activities of dioxygenase enzymes as was obtained in the biotransformation pathway of naphthalene by microalgae *Oscillatoria* sp., strain JCM [56]. Dioxygenase enzyme system is well-known to be in charge for the degradation of PAHs in algal cells [57, 58, 59] just as in bacterial PAH degradation systems but unlike those of fungi which utilizes monooxygenase systems [57].

A number of strategies that could be effectively employed in removal of PAHs include 1. the use of different microalga species; 2. use of mixture of PAHs, and 3. use of microalgae-bacteria consortium (fig. 3). In a study on the mineralization competency for either fluoranthene or pyrene, or a combination of fluoranthene and pyrene by some microalgae species, it was observed that the existence of individual PAH acts synergistically in the elimination of the other PAH [60]. Hong *et al*. (2008) [61] observed that the degradation of fluoranthene by the two diatoms (*Skeletonema costatum* and *Nitzschia* sp.) were slower, compared to phenanthrene, and that the strains also showed comparable or greater competence in the elimination of the Phn–Fla combination than individual Phn or Fla. One of the reports on removal of benzo(a)pyrene (BaP) by two microalgal species *Selenastrum capricornutum* and *Scenedesmus acutus* revealed that *S. capricornutum* can remove 99% of BaP after 15h of exposure, whereas *S. acutus* can remove 95% after 72h of exposure under the same condition [62]. According to [63, 64], the ability to neutralize PAHs from the ecological system and the efficacy of microbial cell population relies mainly on PAH. In another study, *C. sorokiniana* and bacterial consortium was reported to satisfactorily remove PAHs (> 85%) more than the algal system only which indicated the synergistic relationship between the algal-bacterial consortia [65]. Furthermore, algal-bacterial consortium was reported for the degradation of phenanthrene [66] and pyrene under photosynthetic condition. It is cost-effective to use microbial consortium as they have proven to be competent and essential [67]. .

The emergence of biorefinery concept using microalgae feedstock highlights the economic advantage of PAHs bioremediation by microalgae. The microalgae biomass recovered from the process can be converted to biofuel and other value-added products of commercial value [68].

Additionally, there are numerous advantages in the use various bioremediation techniques in the degradation of hydrocarbon compounds such as; it is an environmentally friendly technique with a public acceptance. It converts recalcitrant compounds into harmless products such as biomass, carbon dioxide and water. Bioremediation technologies are relatively cost effective when compared to other remediation strategies. Microorganisms involved in bioremediation process increases exponentially and decrease naturally during remediation process thereby assisting in nutrient cycling compared to the use of chemical additives which may persist in the environment.

Therefore, this study encourages use of alternative sources of materials such as use of bio natural gas other than fossil fuels and means that introduces PAHs in the ecological system. Adequate environmental conditions that support degradation such as moisture, temperature, nutrient content and availability, pH, and use of proven strains of microorganisms with enzyme ability to degrade polycyclic aromatic hydrocarbons should be applied effectively to encourage complete process of biodegradation.

Conclusion

This review discussed the biodegradation and impact of polycyclic aromatic hydrocarbons compounds in the environment. PAHs have deleterious effect in the surroundings because of their toxic nature and the time it takes prior to biodegradation. The pollutant affects the environment negatively by exposing humans to health risks, diminishes microbial populations, reduces soil quality and nutrients, and destroys aquatic lives. Microorganisms are excellent tools for the biodegradation of toxic compounds in nature. Microbial ability to feed on pollutants in the environment remains a key to the bioconversion of the chemicals into harmless forms such as biomass, carbon dioxide and water. The use of eco-friendly technologies rather than means that introduces PAHs in the environment will be helpful in diminishing the concentrations of pollutants in the environment. It is expected that the current research will open up more research in biodegradation of pollutants especially PAHs in the environment so as to find novel microorganisms and enzymes that could effectively degrade pollutants.

Figure 1: Microbial conversion pathway of PAHs, adapted from Cerneglia, 1992 [16].

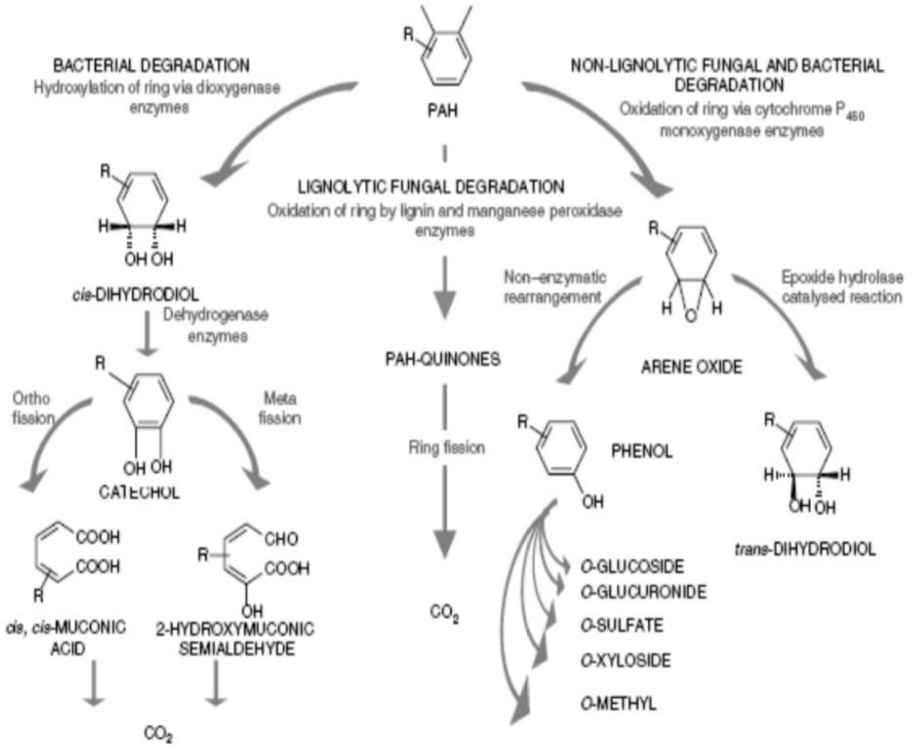

Figure 2: A schematic overview of the possible biodegradation pathway of fluorene by *C. vulgaris* [55].

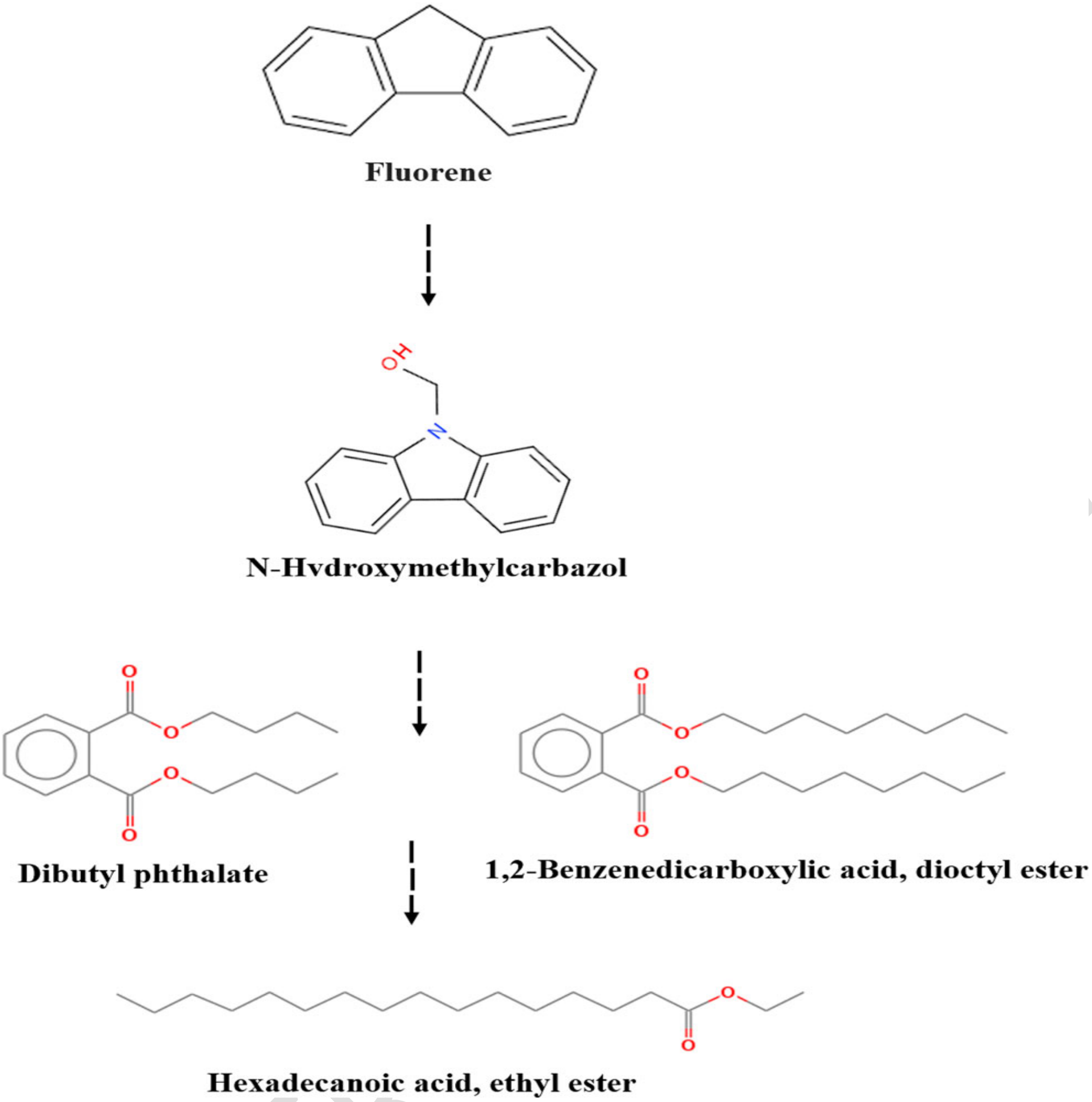

Figure 3: Different strategies for biodegradation of PAHs by microalgae.

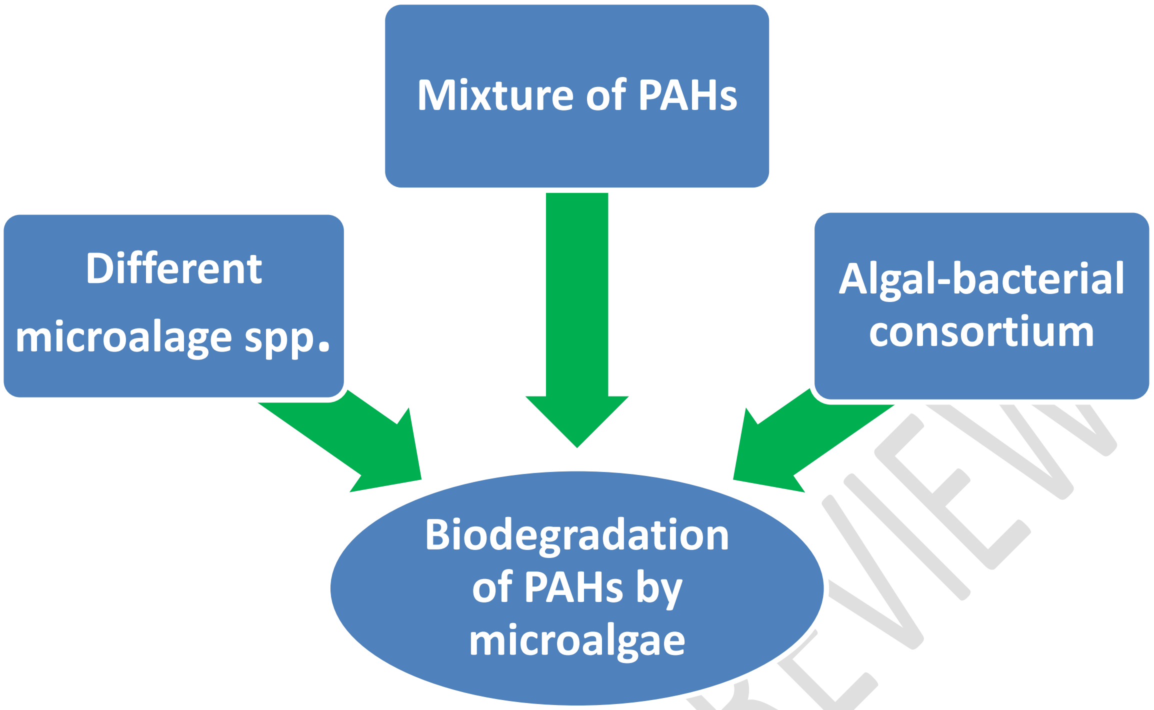

Table 1: Properties of the 16 USEPA PAHs, adapted from Mackay *et al*., 1992 [69].

	Ring number	**Molecular weight**	**Aqeous solubility**	**Log (K_{ow})**	**Vapour pressure (Pa)**
Naphthalene	1	128	31	3.37	1.1E+2
Acenaphthylene	2	152	16.1	4.00	0.9
Acenaphthene	2	154	3.8	3.92	0.3
Flourene	3	166	1.9	4.18	0.09
Phenanthrene	3	178	1.1	4.57	0.02
Anthracene	3	178	0.0045	4.54	0.001
Pyrene	4	202	0.13	5.18	0.0004
Flouranthene	4	202	0.26	5.22	0.00123
Benzo[a]anthracene	4	228	0.011	5.91	2.80E-5
Chrysene	4	228	0.006	5.91	5.70E-7
Benzo[b]flouranthene	5	252	0.0015	5.80	-
Benzo[k]flouranthene	5	252	0.0008	6.00	5.20E-08
Benzo[a]pyrene	5	252	0.0038	5.91	7.00E.07
Dibenzo[a,b]anthracene	6	278	0.0006	6.75	3.70E-10
Indenol[1,2,3-cd]pyrene	6	276	0.00019	6.50	-
Benzo[ghi]perylene	6	276	0.00026	6.50	1.40E-8

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