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A Review on Bacterial Degradation of Benzo[a]pyrene and Its Impact on Environmental Health

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Aerobic

Anaerobic

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Mono

Di-oxygenase

Carcinogenic

ABSTRACT

Benzo[a]pyrene is a polycyclic aromatic hydrocarbon (PAH) having a high molecular weight. Benzo[a]pyrene and other PAHs are induces severe acute or chronic human health hazards and are extremely carcinogenic, mutagenic, immunotoxic, and teratogenic. Microorganisms play a crucial part in the degradation of benzo[a]pyrene from polluted environments. Such micro-organisms synthesize monooxygenase and di-oxygenase enzymes that proceed with the aerobic or anaerobic catabolic degradations of benzo[a]pyrene. Bioaugmentation, biomineralization, and biostimulation methods can be used for the decontamination of benzo[a]pyrene from hydrocarbon contaminated sites. In this review paper, we thoroughly explained the impacts of benzo[a]pyrene pollution on human health and the environment. Further, this study also described various pathways regarding the bio-degradation of benzo[a]pyrene and also an updated overview of future prospects of benzo[a]pyrene biodegradation.

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1 Introduction

Benzo[a]pyrene and hydrocarbons are persistent organic pollutants (POPs), and polycyclic aromatic hydrocarbons (PAHs), and stand for a group of pollutants that are present in the surrounding of the environment (Nzila and Musa 2021). These PAHs pollutants harm our lives and, some have less beneficial effects on the environment and human health (Jong-Su et al. 2009). PAHs are used as raw materials for the manufacture of all hydrocarbons which generate toxic environmental pollutants due to natural and anthropogenic activities (Elyamine et al. 2021). Millions of tonnes of hydrocarbon products spill into soil and water bodies due to oil spills and vehicle emissions (Stogiannidis and Laane 2015) and the major amount of oil spill sites have hazardous conditions for human health and the environment. PAHs are treated to photo-degradation and react with SO_2, NO_2, and O_3 producing stacks of gas and, mutagenic compounds in the atmosphere. The environment contains benzo[a]pyrene in the air, water, and soil, and they can persist there for months or years, the concentration of PAHs in urban air may be ten times higher than in rural environments (Keyte 2015).

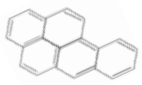
Benzo[a]pyrene and its relevant other PAHs are abundant in nature and cause a wide range of life-threatening issues and are commonly found in oil and fuel-contaminated soil; soil particles absorb the aromatic compound, then cause soil contamination and release it into the environment (Kuppusamy et al. 2017). The Groundwater is also contaminated by Benzo[a]pyrene and PAH compounds, which are continuously released into the environment by incomplete combustion of fuel, during anthropogenic and natural atmospheric activities. In large quantities, water is contaminated by oil spillage sites and causes the death of aquatic species (Montuori et al. 2022) and so, it is very important to control and low emission of benzo[a]pyrene in the environment because it causes mutagenic, carcinogenic, immunogenic and teratogenic (Nzila and Musa 2021). Biological, chemical, and physical remediation are used for decontamination of benzo [a]pyrene, and one of the best methods for microbial degradation, is bioremediation, the most cost-effective and eco-friendly method (Jong-Su et al. 2009; Wang et al. 2018). Breakdown of benzo[a]pyrene, is a mineralization and conversion process and various aerobic and anaerobic bacteria species contribute to this process (Elyamine et al. 2021). Multiple microorganisms and their species have been discovered, which have degraded highly stable and waste polycyclic hydrocarbons. Its degradation rate and other hydrocarbon compounds also depend on various terms such as environmental conditions, availability of nutrients, temperature, pH, microbial load, source of the growth medium, chemical properties, and structure of aromatic compounds (Mortazavi et al. 2022). Oil-eating bacteria produce enzymes and secrete for the utilization of aromatic hydrocarbons; they produce different types of metabolic pathways depending on the optimal condition of the environment (Mishra et al. 2021). Furthermore, biodegradation of benzo[a]pyrene is a more advantageous biological, physical and chemical method, which is used for cleaning up the benzo[a]pyrene-polluted environment (Houshani et al. 2021). PAHs, such as benzo [a]pyrene, have more potential for microbial degradation, the bacterial degrading process by which benzo[a]pyrene is removed from the environment using micro-organisms is known as bioaugmentation. Microorganisms are a major role play in the de-contamination of benzo[a]pyrene in soil and water bodies. Potable water and soil are important elemental requirements for sustainable development, so uncontaminated soil and water can be used for industrial contributions and agricultural production to improve health and economic development (Wang et al. 2018).

Information about microbes in oil spills degrading Benzo[a]pyrene is available in this review, the mechanism of its impact is also fully described and more than 100 species of bacteria from the group's Actinobacteria, Proteobacteria, Firmicutes, Bacteroids, and Cytophaga have been found in the PAH-contaminated areas. It has been discovered that Flavobacterium-Bacteroides assimilates pyrene and has some of the primary abilities of natural self-recovery (Zada et al. 2021). Some normal methods of biodegradation have been used to degrade the PAH compound, but most of these methods have the limitation of being costly and implication is hard under the environmental conditions. For effective PAH-reducing emissions, integrated PAH remediation approaches have also previously been reported. The most prevalent, potentially diversified, and plentiful group of bacteria for benzo[a]pyrene breakdown from the PAHs-contaminated site are reported to include fungi, protozoa, and actinobacteria. Alpha proteobacteria have been observed to be more widespread than beta and gamma proteobacteria among the proteobacteria (Zada et al. 2021; Kumari et al. 2022). We should look for introducing new techniques or novel strains break down of PHAs such as benzo [a]pyrene so the primary goal of this review is to describe the physicochemical properties and microbial biodegradation mechanism by aerobic and anaerobic and as well as to illustrate the health impact on mankind of benzo[a]pyrene.

2 Benzo[a]pyrene

Benzo[a]pyrene and its relevant compound are high molecular weight (HMW) PAHs, and it has great stability due to the presence of an aromatic ring (Nzila et al. 2021). One or more rings fused, yellow, solids, whitish in a specific solvent, angular, low and un-soluble in water, low vaporizing pressure, high melting, and boiling point (Patel et al. 2020), it has high potential toxicity and resistance to biodegradation also and might cause recalcitrant of mutagenic and carcinogenicity (Hsu et al. 2005; Cao et al. 2020). There are a priority list of 16 PAHs given by USEPA (the United States Environmental Protection Agency) which harm biological

Table 1 Properties of Benzo[a]pyrene

Molecular structure	
Molecular Formula	$C_{20}H_{12}$
Molecular Weight	252.31
Solubility in water	0.2 to 6.2 µg/L
Melting point	179[2] °C (354 °F; 452 K)
Boiling point	495 °C (923 °F; 768 K)
No. of benzene rings	5

(humans, animals, plant) and environmental health (Dudhagara and Dave 2018; Dhar et al. 2019).

2.1 Benzo[a]pyrene-related physiochemical properties

Benzo[a]pyrene have five fused benzene ring structure and comes in high molecular weight PAHs. It is a pale yellow color, crystal, slightly soluble in water (hydrophobic), thermodynamically isomer, and stable form in nature (Subashchandrabose et al. 2014). IUPAC's name is 3,4- benzo[a]pyrene and benzo[pqr]tetraphene, and the formula is $C_{20}H_{12}$ (Table 1). This benzo[a]pyrene molecules dissolve in a special solvent like acetone, acetonitrile, dimethyl sulfoxide(DMSO), dichloromethane, hexane, etc., and different PAHs are less water-soluble as their molecular mass increases. (Logeshwaran et al. 2022). Because of the recalcitrance and hydrophobic nature of benzo[a]pyrene, a major concern is ultimately deposited in natural soil and water (Sun et al. 2018; Li et al. 2022).

2.2 Source of Benzo[a]pyrene

Benzo[a]pyrene is a major organic pollutant, one of which is the high molecular weight organic compound PAH and is found not only on earth whereas, but in all spheres, the universes, and planets (Tielens 2005; Dhar et al. 2019; Adeniji et al. 2019). Sources of benzo[a]pyrene are divided into two categories and these are given below:

2.2.1 Natural Source

Benzo[a]pyrene, is emitted from natural forest fires, volcanic eruptions, rangeland fires, and bush fires**.** At natural and some artificial crude oil reservoirs, erosion of sedimentary rock is released by PAHs. It is a pyrogenic source of PAHs, which automatically raises the temperature (Patel et al. 2020).

2.2.2 Anthropogenic sources

Anthropogenic sources are divided into four major categories based on PAH emission routes. They are subcategorized below:

2.2.2.1 Agricultural source

In agricultural sources, PAHs are emitted by the burning of peat cow-dung cake straw (Ravindra et al. 2008; Tsibart et al. 2014) and stubble, rice husk briquettes, bushland and forest, and moorland health (Abdel-Shafy and Mansour 2016).

2.2.2.2 Industrial sources

The industrial sector contributes significantly to PAHs emissions in the environment, particularly in the air through cement production, bitumen and asphalt production, rubber and tire production, metallurgical processes, coal distillation, coal tar and coke production, petroleum residue, gas plant manufacturing, dye, paint, plastic production, and food preservatives (Hesham et al. 2014).

2.2.2.3 Domestic sources account for the majority of PAHs emissions

Cooking (Gupte et al. 2016; Patel et al. 2020), grilled meat foods (Rose et al. 2015), heating, burning activities of coal, oil, gas, garbage, and wood at high temperatures (Johnsen and Karlson 2007); cigarette smoking and fireplaces also come under PAH emission sources from domestic sites. PAH emission is high in daily use, we should bring it to use in less amount little.

2.2.2.4 Automotive sources

Automotive sources of benzo[a]pyrene in environmental contamination include jet engines, trains, exhaust gases, ships, aircraft, and motor vehicles, which secrete a high amount of benzo[a]pyrene (Stogiannidis and Laane 2015).

3 Microbial degradation of Benzo[a]pyrene

Mainly PAHs compounds formed with one and more than three or four benzene rings, namely benzo[a]pyrene (BaP), and its relevant compound polycyclic aromatic hydrocarbons (PAHs). In this study, we will refer to benzo[a]pyrene and other relevant benzene ring compounds as HMW-PAHs because of their long persistent in nature and high toxicity which cause mutagenic and carcinogenic properties (Jong-Su et al. 2009). Since the 1970s, benzo[a]pyrene has been biodegraded and the first reports of its degrading bacteria and bacterial strains cultured in succinic acid and biphenyl during benzo[a]pyrene exposure were published in the 1970s, with *Beijerinckia B-836* being one of the reported bacteria strains (Gibson 1975; Nzila and Musa 2021). *Pseudomonas* strains have degraded benzo[a]pyrene and its substrate salicylate completely removes it (Logeshwaran et al. 2022). Microbes can utilize hydrocarbons through different methods like the bioaugmentation process the addition of mico-organism in hydrocarbon contaminated areas; the biomineralization method is metals removal by microbes (Lawniczak et al. 2020). Metabolism of benzo[a]pyrene by microbial species is an example of biomineralization, bioaugmentation, bioremediation, and pollutant transformation (Kour et al. 2022). With the help of biological, chemical, and physical (Peng et al. 2018) approaches, by way of several bacterial species and other microbes, PAHs compounds are being eliminated from the environment (Tyagi et al. 2011; Adams et al. 2014). Biodegradation demonstrates microbial mechanisms that aid in the ecological recovery of the contaminated sites of benzo[a]pyrene. Specifically, two main types of enzymes identified, which are most abundantly that are monooxygenase and di-oxygenase; which have been characterized by various methods and these enzymes are play important roles in forming cis-dihydrodiols from PAH rings secreted by bacteria and other microbes (Ghosal et al. 2016). In biodegradation mechanisms, enzyme attacks on benzo[a]pyrene rings in the presence of oxygen molecules are called aerobic metabolism. As a first step, the dioxygenase-enzyme helps catabolize oxidation of arenes (organic molecules made from C, H, atoms) which occur in an aerobic environment bacterial metabolic activity to concern for cis-dihydrodiols, catechol (Elyamine et al. 2021), that is an early product (cis-dihydrodiols, catechol) formed by the aerobic bacterial system. This pathway indicates major middle intermediates such as sodium succinate, salicylate (Nzila and Musa 2021), and catechols, which go through intermediates of the tricarboxylic acid (TCA) cycle, in the meta-cleavage pathway, dioxygenase enzyme secretes by bacteria and enzyme attacks on the ortho position of benzo[a]pyrene and intradiol and extradiol product produced during ring cleavage of aromatic compounds (Pimviriyakul et al. 2020). In this system, they have multiple enzymatic systems that involve different types of proteins, iron molecules of nonheme, and NADH (Peng et al. 2008). The dioxygenase (DO) enzyme system, which belongs to a broad family of oxygenases, determines the specific substrate of DO and contains subunits with Rieske [2Fe-2S] centre and mono-central nonheme iron molecules (Gibson and Parales 2000). One of the main contributors to aquatic ecosystem production is algae, which also significantly contributes to the degradation of benzo[a]pyrene in the environment's aromatic pollution (Dell''Anno et al. 2021). However, well-described strains of algae have been shown in previous studies to mineralize or metabolize benzo[a]pyrene and PAHs compounds such as naphthalene, pyrene, phenanthrene, anthracene (Safonova et

Table 2 Benzo[a]pyrene Degrading Microbes and Their Source

S. N.	Microbes	Degraded PAHs	Benzo[a]pyrene source	Reference
1.	*Sphingomonas sp.GY2B;* *S. koreensis ASU-06,*	Benzo[a] pyrene	PAH contaminated soil, Oil-contaminated soil	Tao et al. (2007), Hesham et al. (2014)
2.	*Pseudomonas putida, P. citronellolis,* *P. stutzeri* *P. aeruginosa*	Benzo[a] pyrene	Hydrocarbon contaminated soil and landform used for petrochemical effluent treatment.	Kumar et al. (2006), Zhao et al. (2009), Jacques et al. (2005)
3.	*Bacillus subtilis* *B. megaterium* *B. simplex*	Benzo[a] pyrene	PAH contaminated soil Plankenburg river, oil spill sites.	Lily et al. (2009), Alegbeleye et al. (2017)
4.	*Cellulosimicrobium cellulans CWS 2*	Benzo[a] pyrene	PAH –contaminated soil	Qin et al. (2018)
5.	*Orchrobacterium, Enterobacter cloacae, Rhodococcus sp., Staphylococcus*	Benzo[a] pyrene	Contaminated soil, swab samples from human skin	Arulazhagan and Vasudevan (2009), Sowada et al. (2014)
6.	*Penicillium sp.06, Penicillium sp. CHY-2,*	Benzo[a] pyrene	Petroleum contaminated sites, Antarctic soil	Zheng and Obbard (2003), Govarthanan et al. (2017)
7.	*Fusarium, Fusarium sp. E033*	Benzo[a] pyrene	Crude oil-contaminated Soil, soil site at gas station, and Leaves of *Pterocarpus macrocarpus*	Li et al. (2005), Mineki et al. (2015), Chulalaksananukul et al. (2006)
8.	*Trichoderma sp.*	Benzo[a] pyrene	Petroleum contaminated soil	Mineki et al. (2015)
9.	*Scopulariopsis brevicaulis PZ-4*	Benzo[a] pyrene	PAH-contaminated soil	Mao and Guan (2016)

al. 2005; Chan et al. 2006) (Table 2), but this review focus on most of the bacterial degradation rather than algae.

Benzo[a]pyrene and its organophosphorus pesticides degraded by *Microbacterium* sp. MM1 has a 57.8% of the degraded ability of benzo[a]pyrene in 15 days incubation period at 30° C using a carbon source and energy (Logeshwaran et al. 2022), through a chromosomally encoded path, *B. subtilis BMT4i* (MTCC 9447) degrades benzo[a]pyrene effectively, up to 84.66% in 28 days (Bhatt et al. 2018), *P. aeruginosa PSA5* and *Rhodococcus sp.NJ2* degrades benzo[a]pyrene at 88% and 47% respectively (Mishra and Singh 2014). The aerobic biodegradation process of benzo[a]pyrene by different types of bacterial species usually secretes dioxygenase enzymes: and releases oxygen atoms and the substrate of the compound (di-hydrodiol and enoic). Bacterial species of benzo[a]pyrene degrading and their source are given below (Table 2).

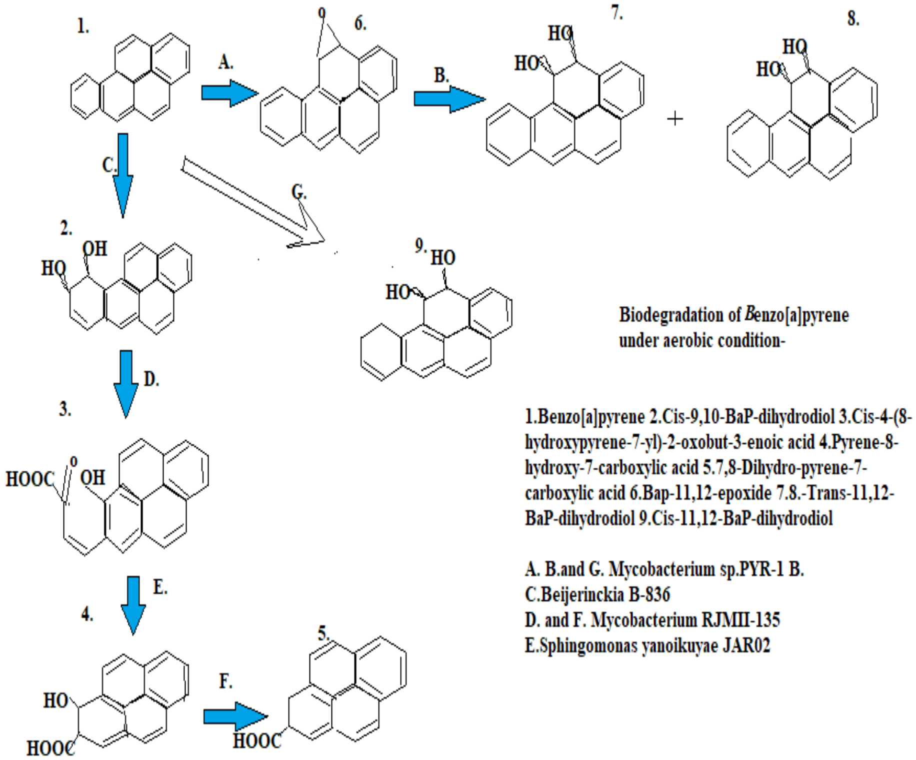
3.1 Benzo[a]pyrene degrades aerobically

Aerobic degradation is the process of the breakdown of a complex compound into simple compounds by microorganisms in the presence of oxygen (Jong-Su et al. 2009). Various microorganisms grow in aerobic conditions; in these conditions, bioventing techniques can use for in-situ bioremediation of benzo[a]pyrene bioventing helps in the cleanup of pollutant and aromatic compounds (Kour et al. 2022). Benzo[a]pyrene has five-aromatic rings and high molecular weight PAH which is one of the most carcinogenic compounds. The low water solubility of benzo[a]pyrene is related to its high recalcitrance and resistance to bacterial and other microbial degradation (Patel et al. 2020). Benzo[a]pyrene is found in relatively high concentrations in environmental samples, and its degradation is limited to catabolic activity by bacterial cultural mass (Nzila et al. 2021). The concentrations of benzo[a]pyrene and relevant hydrocarbons, in soils and water bodies at industrial sites, can significantly depend on the industries, oil-spilling sites, and land activities associated with the contaminated sites (Peng et al. 2008). There is a lack of information about the bacterial degradation of benzo[a]pyrene that has five rings and some bacterial species have previously reported, they have the degrading capability of benzo[a]pyrene including *Mycobacterium sp.*, *Sphingomonas paucimobilis*, and *Stenotrophomonas maltophilia*, as well as *S. maltophilia VUN 10,003*, that degraded benzo[a]pyrene by 22% after 14 days of incubation period and 37°C temperature (Juhasz et al. 2002) when grown on fluoranthene, *S. paucimobilis EPA 505* degraded 33% of benzo[a]pyrene (Story et al. 2001).

During the dehydration of benzo[a]pyrene, *Beijerinckia sp. strain B1* degrades Benzo [a]pyrene into cis-9,10-BaP-dihydrodiol and 7,8-BaPdihydrodiol are produces using their enzymes secreted by *Beijerinckia sp. strain B1*(Gibson 1999). *Mycobacterium sp. strain RJGII-135* aids in the forms of ring cleavage metabolites and forms 7,8-BaP-dihydrodiol (Schneider et al. 1996) the transformation of oxidation of the Benzo[a]pyrene ring. Benzo[a]pyrene rings metabolites degrade using dioxygenase enzyme, one ring oxidized in one ring and comes forms into cis-4-(8-hydroxypyrene-7-yl)-2-oxobut-3-enoic acid and 7,8-dihydrobenzo[a]pyrene. In this metabolism, enzymes attack the 4,5,7,8, and 9,10 positions of benzo[a]pyrene by using *Sphingomonas yanoikuyae JAR02 metabolites* (Nzila et al. 2022). Pyrene-8-hydroxy-7-carboxylic acid was synthesized by Rentz et al. (2008) and cis-4-(8-hydroxypyrene-7-yl)-2-oxobut-3-enoic acid (Mishra and Singh 2014). In this metabolism, the enzyme attacks the 9,10- and 7,8-positions of benzo[a]pyrene. The alpha subunit of the PAH ring is broken up by referring to the different dioxygenases that are produced from gene encoding and it is concerned with PAH metabolism and especially benzo[a]pyrene metabolic activity by bacteria (Ghosal et al. 2016) and was defined as benzo[a]pyrene cis 7,8 dihydrodiol catabolized into 7,8 dihydro-pyrene-8-carboxylic acid by Cebron et al. (2008); Lozada et al. (2008) (Figure 1).

On PAHs contaminated sites, *Mycobacterium sp. PYR-1* (Bhatt et al. 2018) degraded benzo[a]pyrene into benzo[a]pyrene-11,12-epoxide and trans-11,12-benzo[a]pyrene-dihdrodiol (Kim et al. 2007). Other pathways of benzo[a]pyrene degradation *Beijerinckia sp. strain B-836* aids in the metabolism of this compound, and after its metabolism degrades cis-9,10-BaP-dihydrodiol, *Mycobacterium RJMII-135* uses this substrate and converts it to cis- 4-(8-hydroxypyrene-7-yl)-2-oxobut-3-enoic acid. The above bacterial strains initiate the oxidation of cis-4-(8-hydroxypyrene-7-yl)-2-oxobut-3-enoic acid and the formation of pyrene-8-hydroxy-7-carboxylic acid by *Sphingomonas yanoikuyae.*, *Mycobacterium RJMII-135* reduces hydroxyl groups and produces 7,8-dihydro-pyrene-7-carboxylic acid (Rentz et al. 2008). *Mycobacterium sp. PYR-1* initiates an oxidation reaction and attaches an oxygen group to the 11,12 position of benzene rings, releasing hydroxyl groups that form two molecules of trans-11,12-BaP-dihydrodiol (Figure 1) (Nzila and Musa 2021).

Benzo[a[pyrene degradation pathway, was initiated by monooxygenase and dioxygenase enzymes attacks on the 11,12 position of benzo[a]pyrene rings, which concluded in the formation of cis and trans-11,12-BaP-dihydrodiol. Moody et al. (2004) have revealed new production methods for benzo[a]pyrene degradation in *M. vanbaalenii PYR-1* and its Cytochrome P-450 enzymes help in the catabolic activity of benzo[a]pyrene and further catabolized into dimethoxy benzo[a]pyrene *via* hydroxyl methoxy benzo[a]pyrene (Abdel-Shafy and Mansour 2016) and the hydrolysis reaction produces benzo[a]pyrene epoxide. This cytochrome P-450 enzyme is a superfamily of heme enzymes and is found in all biological domains (Bak et al. 2011; Bhandari et al. 2021).



Biodegradation of Benzo[a]pyrene under aerobic condition-

1.Benzo[a]pyrene 2.Cis-9,10-BaP-dihydrodiol 3.Cis-4-(8-hydroxypyrene-7-yl)-2-oxobut-3-enoic acid 4.Pyrene-8-hydroxy-7-carboxylic acid 5.7,8-Dihydro-pyrene-7-carboxylic acid 6.Bap-11,12-epoxide 7.8.-Trans-11,12-BaP-dihydrodiol 9.Cis-11,12-BaP-dihydrodiol

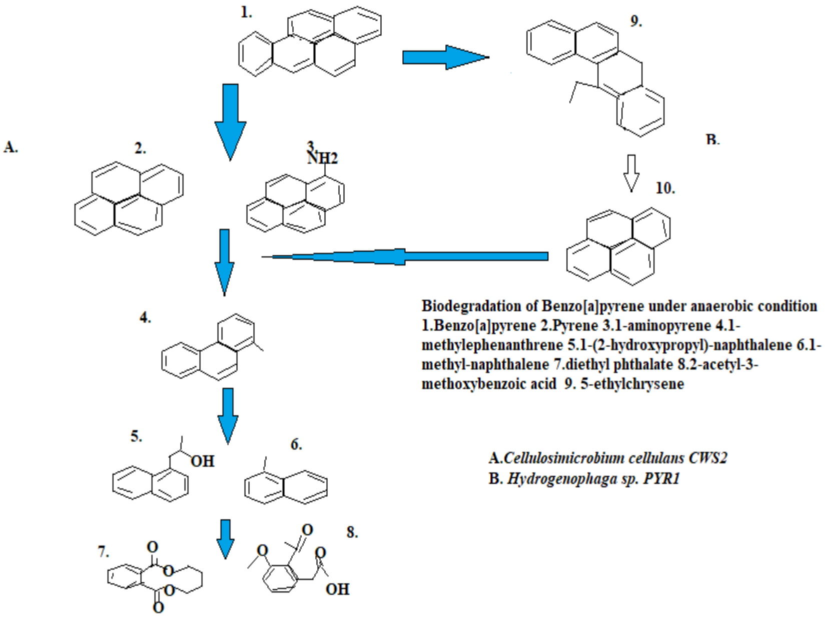
A. B.and G. Mycobacterium sp.PYR-1 B.
C.Beijerinckia B-836
D. and F. Mycobacterium RJMII-135
E.Sphingomonas yanoikuyae JAR02

Figure 1 Benzo[a]pyrene Degradation under Aerobic Condition

3.2 Anaerobic Benzo[a]pyrene degradation

Anaerobic degradation is the activity of breaking down a complex compound into simple compounds by microorganisms in the absence of oxygen conditions in the environment. In this pathway, the breakdown of aromatic rings (Chen et al. 2016) by bacterial reduction occurs because of an enzymatic attack on benzene rings secreted by microorganisms. According to benzo[a]pyrene degradation, it was completely oxidized by a mixture of bacteria during the denitrification process (Nieman et al. 2001) and the final product is carbon dioxide and methane (Aydin et al. 2017). Various studies have been conducted on the biodegradation of benzo[a]pyrene by single strains of bacteria under anaerobic conditions. We are aware that the PAH compound, benzo[a]pyrene has a high molecular weight, and *Pseudomonas* sp. JP1 was the first sp. that has specific characteristics and degrades (Liang et al. 2014). *Cellulosimicro biumcellulns CWS2* degraded 78.8% benzo[a]pyrene in 13 days and the occurrence of this species produces pyrene and 1-aminopyrine NH2 groups attached to 1 position of benzo[a]pyrene on contaminated sites (Qin et al. 2018). Opening benzo[a]pyrene rings produce 1-methyl phenanthrene, and attaching hydroxyl groups to two positions produces 1-(2-hydroxypropyl)-naphthalene and 1-methyl-naphthalene. In this reaction, oxidation of this substrate changes it into diethyl phthalate and 2-acetyl-3-methoxybenzoic acid (Figure 2). *Hydrogenophaga sp. PYR-1* degrades benzo[a]pyrene. Furthermore, this species attacks the 5-position of Benzo[a]pyrene rings, producing 5-ethylchrysene and degrading pyrene contents. Therefore, in these mechanism studies, only pyrene, phenanthrene, 1-aminopyrene, 1-methylphenanthrene, 1-(2-hydroxypropyl)-naphthalene, 1-methyl-naphthalene, diethyl phthalate, and 2-acetyl-3-methoxybenzoic acid from the substrate produced by micro-organism enzymatic secretion (Nzila et al. 2021).

Magnetospirillum magneticum strain AMB-1, *Azoarcus sp. EbN1*, *Rhodopseudomonas palustris strain CGA009*, Thauera aromatica, *Geobacillus metallireducens GS-15*, and *Syntrophus aciditrophicus strain SB*; these bacterial strains are famous for anaerobic degradation of aromatic compounds. Cleanup of heavy metals from PAHs using *Pseudomonas putida KBM-1* and *P. putida-CZ1* helps in the binding of Cu-and Zn for chemical transforming and biomass for the cleanup of PAHs contaminated sites in anaerobic conditions (Qin et al. 2017). Carboxylic groups play the main role in the metal-binding in anaerobic conditions, create intermediate substrates and decrease its degradation rates (Kong et al. 2022). Cu (II) (copper) is absorbed by anaerobic bacteria species and other microorganisms in benzo[a]pyrene metabolism under anaerobic conditions, reducing benzo[a]pyrene transport (Chen et al. 2007).



Biodegradation of Benzo[a]pyrene under anaerobic condition 1.Benzo[a]pyrene 2.Pyrene 3.1-aminopyrene 4.1-methylephenanthrene 5.1-(2-hydroxypropyl)-naphthalene 6.1-methyl-naphthalene 7.diethyl phthalate 8.2-acetyl-3-methoxybenzoic acid 9. 5-ethylchrysene

A.*Cellulosimicrobium cellulans CWS2*
B. *Hydrogenophaga sp. PYR1*

Figure 2 Benzo[a]pyrene degradation under Anaerobic Condition

4 Impact of Benzo[a]pyrene on Human Health

Benzo[a]pyrene is obtained from the environment through human and other animal contact, which is hazardous and unhealthy (Srogi 2007). Despite the case that benzo[a]pyrene is ubiquitous in environmental and food-borne; humans are continuously exposed to it on a daily need through engine exhaust, air, and water. It is widely used in smoking, tobacco, grilling meat, and preparing foods (Bukowska et al. 2022). Benzo[a]pyrene only attacks cells once before being activated by the cytochrome P450-dependent monooxygenase enzyme and converted into other substrates (Peng et al. 2008). Toxically, the substrate binds to DNA cells covalently, and oxygen is produced by micro-organisms during benzo[a]pyrene metabolism, which damages cellular molecules (Rubin 2001; Umannová et al. 2011). When benzo[a]pyrene biotransforms into dihydroxy-epoxy-tetra hydro-benzo[a]pyrene, it attaches to DNA and forms DNA adducts, which causes mistakes in DNA replication and finally unchecked cell division or cancer. Banzo[a]pyrene is a known carcinogen and it also disrupts the immune system's growth and operation, in addition to affecting the fertility of the progeny. After benzo[a]pyrene harmed human health by causing teratogenicity, immunotoxicity, carcinogenicity (Borji et al. 2020; Darajeh et al. 2020), mutagenicity, and neurotoxicity (Burchiel 2005), it was discovered that it also harmed animals (Figure 3). Tumours are induced in different organs during the use of laboratory animals for experimental tests. According to the International Agency for Research on Cancer, it is classified as a group I carcinogen (IARC 2010; Lindeman et al. 2011). According to the WHO (2003), a daily intake of 257μg/day orally causes tumour and carcinogenic effects when in direct contact with the subcutaneous route (WHO 2003).

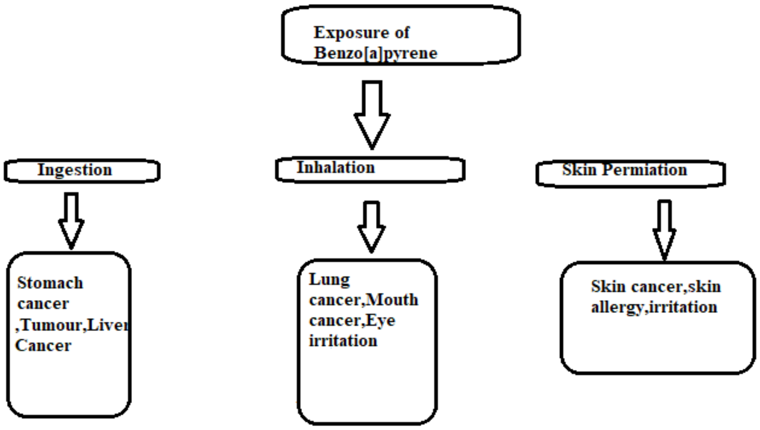


Figure 3 Benzo[a]pyrene Exposure to Human health

4.1 Other Benzo[a]pyrene Side Effects

According to Kungwani et al. 2022, the major side effects of benzo[a]pyrene cause environmental pollution and are responsible for global warming. The major effects of benzo [a]pyrene pollution, according to this study, are contamination of oceans, rivers, ponds, land, and air, loss of animal species, and loss of agricultural productivity due to soil contact with the oil spill (Bukowska et al. 2022). Waterbody species have died in large numbers due to contamination with benzo[a]pyrene and its relevant compounds (Patel et al. 2020).

5 Factors Influencing the Degradation of Benzo[a]pyrene

Bacterial and other microbial degradation of benzo[a]pyrene and its relevant rings fused compounds are affected by environmental physicochemical factors such as various temperatures, pH level, oxygen level, nutrient (energy source) availability, light, and salinity (Rajpara et al. 2017; Zheng et al. 2018).

6 Conclusion and Future perspectives

Benzo[a]pyrene is one of the known toxicants among aromatic compounds. Benzo[a]pyrene has high stability in the environment and severe hazard to human health and causes mutagenicity, carcinogenicity, immunogenicity, and taratogenicity. The main source of benzo[a]pyrene contamination is a petroleum processing plant, petrol pump station, automobile, and garage. Due to their recalcitrant in benzo[a]pyrene, they enter to the biological system through the food chain. Benzo[a]pyrene binds to DNA (DNA adducts forming) genetic material covalently and causes mistakes in DNA replication that ultimately result in unregulated cell division or carcinoma and causes in humans and animals. Bacterial degradation has been reported in previous, aerobic bacteria are *Mycobacterium sp. PYR-1*, *Mycobacterium RJMII-135 sp.*, and anaerobic bacteria are *Pseudomonas* sp. JP1, *Cellulosimicrobium* sp., *Magnetospirillum magneticum strain AMB-1*, *Azoarcus sp. EbN1*, *Rhodopseudomonas palustris strain CGA009*, Thauera aromatica, *Geobacillus metallireducens GS-15*. In co-metabolism anaerobic degradation, *Cellulosimicro biumcellulns CWS2* have generated diethyl phthalate, 2-acetyl 3-methoxybenzoic acid and *Hydrogenophaga sp. PYR1* generated pyrene. In the aerobic degradation pathway, *Mycobacterium sp. PYR-1* converted benzo[a]pyrene into benzo[a]pyrene-11,12-epoxide, trans-11,12-benzo[a]pyrene-dihydrodiol and cis-11,12-benzo[a]pyrene-dihydrodiol and *Mycobacterium RJMII-135 sp.* converted pyrene-8-hydroxy-7-carboxylic acid into 7,8-dihydro-pyrene-7-carboxylic acid in the form of by-product. Degradation and mineralization of benzo[a]pyrene are depends on microorganism and their environmental conditions. Most of the studies were consistent with the degradation of low molecules PAHs but, limited work has been published on benzo[a]pyrene with high molecular weight due to their polycyclic structure. Future work should be revealed in their detailed degrading pathway and enzyme involved during its detoxification. Further, the future process of benzo[a]pyrene degradation are biostimulation, bioventing, and biosparging; the process may be more effective and environmentally sustainable for the benzo[a]pyrene de- contamination from the polluted sites.

Conflict of Interest

All authors declare that they do not have any conflict of interest.

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