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Bioremediation of Carbamazepine using Bacteria: A Review

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ABSTRACT

Carbamazepine is one of the pharmaceutical compounds that cause pollution. Bioremediation is chosen as the suitable method for degrading carbamazepine. The bioremediation of carbamazepine is achieved by determining the characteristics of bacteria and the source of bacteria used in the degradation of carbamazepine. Gram-negative bacteria are more favourable compared to gram-positive bacteria. Gram-negative bacteria obtained from sludge samples with various contaminants degraded carbamazepine efficiently at 100 %. pH 7 and temperature at 25 °C are optimal conditions that provide optimum results in degrading carbamazepine. MSS media is the preferred medium for bacteria as it degrades carbamazepine into the source of carbon. These identified gaps in the study provide basic information and shed light on future mechanism and application studies.

1. Introduction

Pharmaceutical compounds pollution has raised concern as the presence of the compounds in the aquatic environment increased. Many pharmaceutical compounds are not completely removed by the wastewater treatment plant. Examples of pharmaceutical compounds found in wastewater are carbamazepine, acetaminophen, diclofenac and ibuprofen. Carbamazepine is mostly found in concentrations between 1 and 10 μgL^{-1} in treated sewage and at 610 ngL^{-1} [1, 2]. Bhattacharya *et al.,* [3] stated that and assessment should be conducted when the active ingredient of carbamazepine is discovered to be equal to or greater than 1.0 gL^{-1} in an aquatic environment. Carbamazepine is one of the pharmaceutical compounds with chronic toxicity. The elevated concentrations are due to enzymatic reactions in the treatment plant cleaving the glucuronide conjugates of carbamazepine [4]. It causes endocrine disruption the development of antibiotic resistance in human pathogens and severe hypersensitivity reaction. Paltiel *et al.,* [5] also stated that carbamazepine is known

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teratogenic in pregnant women. These negative impacts lead to carbamazepine is listed as one of the emerging pollutants and thus treatment methods are also addressed.

Bioremediation is one of the popular treatment methods for carbamazepine. Bioremediation needs appropriate environment for microbial growth and enzymatic activity [6]. The presence of a degrading microbial population, the concentration of pollutants and the environmental conditions such as pH, temperature and nutrient are factors that affect bioremediation [7]. In general, pH 7 and 25° C are the optimal pH and temperature in degrading carbamazepine [1, 8-11]. A high rate of ATP synthesis increases bacterial population, thus degradation performance increases. Temperature influences microbial physiological reactions, hence it can speed up or slow down the bioremediation process, thus affecting bioremediation efficiency. Medium is the source of nutrient for microorganisms where it utilizes the organic pollutants as the nutrients for growth and energy through specific mechanisms [6].

Algae, fungi and bacteria are among the microorganisms involved in carbamazepine bioremediation. Microorganisms consume the bulk organics present in wastewater and sludge which serve as the principal sources of nutrients [9]. The advantages of using this method are it is widely accepted and sustainable [12]. However, bioremediation has limitations such as it is only applicable to biodegradable substances and completely degradation may take long period of time. Thus, selecting the appropriate microorganism for bioremediation is crucial for accelerating the process and resolving issues.

2. Bioremediation for Carbamazepine

The advantages and disadvantages of microorganisms utilised in bioremediation are listed in Table 1.

Table 1
Types of microorganisms used in bioremediation of carbamazepine

Microorganisms	Advantages	Disadvantages	References
Algae	• A procedure that does not require oxygen in light circumstances • Do not produce toxic substances	• Low rate of survival • High production cost	[13] [14]
Fungi	• Natural decomposers of waste matter	• Low rate of survival • Slow process	[15]
Bacteria	• High rate of survival • Can detox the organic compounds	• The application of bacteria in this field is limited	[16-17]

Based on Table 1, algae have increased the efficiency in degrading pharmaceutical compounds. Algae are chlorophyll-containing organisms that photosynthesis to degrade carbamazepine into basic compounds such as carbon dioxide and water [13]. Carbamazepine is mostly converted and degraded by degradation and occasionally leads to mineralization [12]. Sensitivity and tolerance of algae may change and affect removal efficiency after exposure to the pollutants. Algae have several advantages, including it does not require oxygen and does not produce toxic substances during bioremediation. However, algae have a low rate of survival and high production cost. Singhal *et al.,* [14] stated that the high production cost is due to algae maintenance and algae excessive growth, which require continuous cleaning.

Fungi are recognised as natural waste decomposers because they may secrete a variety of extracellular enzymes that help to decompose waste. Extracellular enzymes decrease carbamazepine concentration by cleaving complicated chemical bonds [15]. Table 1 shows that one of the advantages of using fungi is extracellular enzymes improve the degradation efficiency. However, fungi have a limited rate of survival as well as the process and procedure are time-consuming.

Bacteria evolve effective adaption mechanisms in harsh environments, utilise contaminants as possible energy sources and finally easily live in contaminated environments [16,18]. Bacteria detoxify organic compounds via oxidative coupling that is mediated by oxidoreductases [17]. Microbes obtain energy by cleaving chemical bonds and assisting the flow of electrons from a reduced organic substrate (donor) to another chemical molecule, which is mediated by enzymes (acceptor). The pollutants are eventually converted to harmless compounds during oxidation-reduction processes (Table 1). However, different types of bacteria show various degradation of performance in degradation study. To overcome this, suitable and highly efficient bacteria are selected according to the condition of the environment.

Bacteria is a potential degrader of carbamazepine where it outperformed algae and fungi in terms of survivability [10]. Bacteria are chosen as the most effective degrader due to their high survival rate and adaption strategies where the mechanism in protecting bacterial cell is due to the efflux of toxic compounds from the membrane compartment [18]. The selection of bacteria used is important in increasing the efficiency of carbamazepine degradation.

3. Bacteria for Carbamazepine Degradation

The gram-positive and gram-negative bacteria efficiency in degrading carbamazepine are shown in Table 2. Gram-negative bacteria are higher efficiency compared to gram-positive bacteria because it has thin coating of peptidoglycan cell walls that is peptidoglycan. Due to the increased protection offered by the impermeable outer membrane and hydrocarbon, gram-negative bacteria are more resistant to antimicrobial treatments than gram-positive bacteria [19]. There are limited studies comparing the efficiency of gram-positive bacteria versus gram-negative bacteria in the degradation of carbamazepine in a similar condition study.

Single strain or mixed cultures of bacteria are used in the bioremediation method [9]. Based on Table 2, single strain culture generally has lower efficiency in degrading carbamazepine compared to mixed culture. Single strain culture is the most used in degradation of organic compounds. The benefit of employing single strain culture is that the bacterial strains and activities may be tracked over time using culture-based or molecular approaches to assess bacterial growth [19]. However, single strain culture biodegradation methods do not accurately represent the behaviour of environmental microorganisms during bioremediation in natural environments [20].

Table 2
Gram-positive and Gram-negative bacteria in degrading carbamazepine single strain VS mixed culture

Type of bacteria	Bacteria	Culture of bacteria	Concentration of Carbamazepine (mgL^{-1})	Efficiency (%)	References
Gram-positive bacteria	Streptomyces MIUG 4.89	Single strain culture	0.2	30	[11]
	Streptomyces SNA	Single strain culture	0.2	30	[11]
	Streptomyces MIUG 4.89	Single strain culture	0.2	35	[11]
	Acetinobacter US1., Bacillushalodurans, Micrococcus SBS-8, Pseudomonas putida	Mixed bacteria culture	0.1	60	[9]
	Rhodococcus rhodochrous	Single strain culture	9.5	15	[21]
Gram-negative bacteria	Serratia sp.,	Single strain culture	0.75	0	[22]
	Paraburkholderia xenovorans LB400	Single strain culture	10	100	[8]
	Sphingobacterium sp., Chryseobacterium sp., Alcaligenes sp.	Mixed bacteria culture	0.025	With acetate: 20 No acetate: 10	[23]
	Aquicella sp., Microvirga sp., Rhodobacteraceae	Mixed bacteria culture	50 ngg^{-1} 500 ngg^{-1} 5000 ngg^{-1}	Aerobic: 12.8-14.5 Anaerobic: 6.2-14.9	[24]
	Spinghomonas sp., unclassified family of Spinghomonadaceae and Xanthomonandaceae	Mixed bacteria culture	5000 ngg^{-1}	More than 25	[24]
Gram positive + Gram negative	Rhodococcus + Lefsonia	Mixed bacteria culture	10 mg/L	100	[20]

A mixed bacteria culture usually exhibit a high degradation performance or resistance towards extreme environment conditions [19-20]. Different strains of bacteria in a mixed bacteria culture aid in the transformation of the contamination into various forms of degradation products. There are limited studies comparing the efficiency of mixed bacteria culture and single strain bacteria culture in degrading carbamazepine. In addition, diverse microbial interactions are important for successful biodegradation as it represents the real and application situations [20]. The synergistic or antagonist interactions among members of the associations of bacteria significantly affect the degradation performance, intermediates compounds and final products. As a result, the consortium selection of diverse microbial strains is critical.

Table 3 shows the sources of carbamazepine degrading bacteria. Bacteria obtained from sludge sample are higher efficiency compared to bacteria obtain from fossil fuel combustion waste. This is due to municipal waste contain various type of pollutants [25] and bacterial strains evolve to degrade carbamazepine efficiently [1]. The carbamazepine contaminated source isolated bacteria has higher efficiency compared to other sources. However, there are limited studies on the efficiency of bacteria obtain in different sources in degrading carbamazepine.

Table 3
Source of bacteria in degrading carbamazepine

Bacteria	Source of bacteria	Efficiency (%)	References
Streptomyces MIUG 4.89	Sludge sample from wastewater treatment plant	30	[28]
Streptomyces SNA	Sludge sample from wastewater treatment plant	30	[28]
Streptomyces MIUG 4.89	Sludge sample from wastewater treatment plant	35	[28]
Acetinobacter US1., Bacillushalodurans, Micrococcus SBS-8, Pseudomonas putida mixed bacteria culture	Sludge sample from municipal waste	60	[9]
Rhodococcus rhodochrous	Fossil fuel combustion waste	15	[21]
Serratia sp.,	Sludge sample from municipal solid waste	0	[22]
Paraburkholderia xenovorans LB400	Sludge sample from municipal solid waste	100	[8]
Sphingobacterium sp., Chryseobacterium sp., Alcaligenes sp. mixed bacteria culture	Soil	With acetate: 20 No acetate: 10	[23]
Aquicella sp., Microvirga sp., Rhodobacteraceae mixed bacteria culture	Sludge sample from wastewater treatment plant	Aerobic: 12.8-14.5 Anaerobic: 6.2-14.9	[24]
Pseudomonas CBZ-4	Sludge sample from municipal solid waste	46.6	[10]
Spinghomonas sp., unclassified family of Spinghomonadaceae and Xanthomonandaceae mixed bacteria culture	Sludge sample from municipal solid waste	More than 25	[24]

The medium affects bacteria survival and thus plays an important role in carbamazepine degradation. Table 4 shows medium used for carbamazepine degradation. There are two types of mediums which are rich and poor medium. Basal and Bushnell Haas media are rich medium which contain all nutrients [26]. MSS, Dominic and Graham media and phosphate buffer are categorized as poor medium that lack of nutrients [27]. Poor medium has higher efficiency in degrading carbamazepine compared to rich medium. Bacteria is tolerance to toxicity in rich medium as bacteria can be grown in rich medium without the addition of further media enrichment [28]. The poor medium MSS media is commonly used because the bacteria are affected by the absence of nutrients involved in the degradation process. As MSS media lack of carbon, bacteria degrade and utilize carbamazepine to obtain source of carbon as nutrient for survival and growth. However, there are limited studies comparing the types of medium used, especially rich and poor medium in degradation of carbamazepine. Using different types of medium in degrading carbamazepine are the gap of study to further evaluate mechanism for degradation.

Table 4
Medium used in degrading carbamazepine

Parameter	Name of bacteria	Medium used	Efficiency (%)	References
Rich Medium	Streptomyces MIUG 4.89	Basal media	30	[28]
	Serratia sp.,	Bushnell Haas media	0	[22]
Poor medium	Streptomyces SNA	MSS media	30	[28]
	Streptomyces MIUG 4.89	MSS media	35	[28]
	Paraburkholderia xenovorans LB400	Phosphate buffer	100	[8]
	Sphingobacterium sp., Chryseobacterium sp., Alcaligenes sp. mixed bacteria culture	MSS media	With acetate: 20 No acetate: 10	[23]
	Pseudomonas CBZ-4	Dominic and Graham media	46.6	[10]

4. Conclusions

In this study, the evaluation of bioremediation of carbamazepine using bacteria is reviewed. It is found that gram-negative bacteria have higher efficiency in degrading carbamazepine compared to gram-positive bacteria. There are limited studies comparing the efficiency of gram-positive bacteria versus gram-negative bacteria in the degradation of carbamazepine The mixed bacteria culture for degradation of carbamazepine is applicable in comparing the efficiency of gram-positive bacteria versus gram-negative bacteria. However, there are limited studies comparing the efficiency of mixed bacteria culture and single strain bacteria culture in degrading carbamazepine. The source of bacteria also plays a major role in increasing the efficiency of carbamazepine degradation. The bacteria isolated from contaminated sources are preferrable. There are limited studies on the efficiency of bacteria obtain from different sources in degrading carbamazepine. When degrading carbamazepine, a poor medium is preferred since the bacteria degrade and utilize the contaminants as the source of carbon. Using different types of medium in degrading carbamazepine is also a gap of study to further evaluate degradation mechanism for degradation.

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