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Acinetobacter as Model Organism: Environmental and Biotechnological Applications

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Abstract

Among different microbial groups present in nature, *Acinetobacter* holds an important place due to its profuse presence in different environments like freshwater, soil, solid wastes, and wastewater. Versatile metabolic characteristics of different species of genus *Acinetobacter* have been fascinating emergent interest in different fields of environmental, medical, and biotechnological perspectives. Various members of this genus are recognized to be involved in biodegradation, treatment, and removal of various inorganic and organic hazardous wastes. Some *Acinetobacter* strains are also well-characterized to produce industrially valuable bioproducts. Because of its ecological importance, the genus *Acinetobacter* is also considered a model organism for environmental and industrial microbiological studies. Various Bioproducts including Biopolymers, Bioemulsifiers, Bioreporters, and Biosurfactants are also produced by different species of *Acinetobacter*. This review recapitulates the practicality and various applications of *Acinetobacter* strains in the field of environmental biotechnology.

Keywords: *Acinetobacter*, biodegradation, bioemulsans, bioproducts, biosurfactant, lipases, polysaccharides.

1. Introduction

Acinetobacter is a Gram-negative bacterium that belongs to the family of γ-Proteobacteria and Pseudomonadales order. It is an oxidase-negative, and strictly aerobic bacterium. Both pathogenic and nonpathogenic species are included in this genus (deBerardinis et al, 2009). *Acinetobacter* spp. are prevalent in nature and can be isolated from human skin and other living organisms. They can also be obtained from water and soil. They are strictly aerobic, non-motile bacteria. While examine under the microscope, they appear as gram-negative coccobacilli which are usually arranged in pairs. They can utilize different carbon sources for their growth. For their culture, comparatively simple media, like trypticase soya agar and nutrient agar are usually used. (de Breij et al, 2010). The genus *Acinetobacter* includes various species which have been appealing much attention in both biotechnological and environmental applications. Different *Acinetobacter* strains are identified to be concerned with the biodegradation of a variety of various pollutants like amino acids (analine), benzoate, and biphenyl along with chlorinated biphenyl, phenol, acetonitrile, and crude oil. They are also involved in heavy metals and phosphate removal from wastewater. Particular strains of diverse *Acinetobacter* spp. are developed for the bioremediation purpose of recalcitrant and other detrimental organic chemicals in recent years. These strains are also used for the bioengineering of different enzymes and diagnostic constituents (Luckarift et al, 2011). Conventionally, the main focus of research regarding the genus *Acinetobacter* includes

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Table 1 Examples of usage of *Acinetobacter* spp. for the bioremediation of heavy metals contaminated soils and effluents

Contaminated environment	**Species/strains used**	**Reference**
Effluent from tannery or Textile industry containing heavy metals	*Acinetobacter* spp.	Ugoji and Aboaba, 2004 Srivastava and Thakur, 2007
Digested sewage sludge containing Lead	*Acinetobacter calcoaceticus var. anitraus*	Mak et al, 1990
Wastewater or Activated sludge contaminated with Chromium	*Acinetobacter* spp. *A. haemolyticus*	Francisco et al, 2002 Pie et al, 2010
Silver contaminated photographic wastewater	*Acinetobacter baumannii* BL54	Ohadi et al, 2017

naturally occurring transformation, hydrocarbon degradation, and organic compound utilization. The latest research areas for the genus *Acinetobacter* are various applications in the field of biotechnology, genomes analysis, and their evolution, the pattern of antibiotic resistance, and identification of pathogenic strains. (Jung & Park, 2015). Different *Acinetobacter* strains are also sound acknowledged fermentable bacteria because of their involvement in the manufacturing of various intra-and-extracellular economic products like bio emulsifiers, proteases, lipases, cyanophycine, and multiple types of biopolymers (Abdel-El-Haleem, 2003).

Therefore, the main emphasis of this review is on the use of different *Acinetobacter* strains in the bioremediation of several environmental pollutants and different applications in the field of biotechnology. This review also concerns various bioproducts which are produced by the genus *Acinetobacter*.

2. Bioremediation of Industrial Contaminants

Numerous toxic compounds can disperse and persist to a higher magnitude in the environment (Vasudevan & Mahadevan, 1992). Bioremediation is a comparatively economical method. In this process, hazardous substances can be converted into non-toxic or less-toxic forms by using microorganisms. Among different microorganisms, *Acinetobacter* is the one which can reduce and eliminate a widespread array of inorganic and organic compounds.

2.1 Heavy Metals

Heavy metals are the most important toxic component present in industrial wastewater. Before disposal they should be treated properly, otherwise, they become hazardous to the environment. Among several kinds of heavy metals, chromium (VI) has oxidizing, mutagenic, and carcinogenic properties and so it is considered an extremely hazardous metal. (Cheung and Gu, 2007). For developing an efficient bioremediation approach, a few things should be considered such as the choice of a suitable microbial strain, which can tolerate and minimize high levels of toxicants, and also to study the interaction between microbe and toxicant. (Das and Mishra, 2010). A study of moderately halophilic eubacteria regarding metal intolerance showed that strains of different species of *Acinetobacter* were found to be most tolerant against heavy metals. The majority of stains show tolerance to eight different kinds of metal ions (Kholodii et al, 2004). Because of the ability to transform or store heavy metals, *Acinetobacter* strains could hypothetically be misused for the bioremediation purpose of soil and water contaminated with metals. (Table 1).

2.2 Pesticides

Some strains of *Acinetobacter* also have applications in the bioremediation of water and soil contaminated by a wide range of pesticides. The degradation of pesticides can be determined by a feature of the plasmid. Lamb et al in 2000 stated the genetic engineering strain BD413 of *Acinetobacter* spp. which represents the cytochrome P450 xenobiotic-metabolizing enzyme CYP105D1 derived from specie *Streptomyces griseus*. The genetically engineered strain can degrade various organic pollutants as well as chlortoluron, which is considered a greater achievement in the process of bioremediation

2.3 Hydrocarbons & Aromatic Compounds

Among different characteristics of *Acinetobacter*, one common characteristic is aromatic compound utilization, since the starting of taxonomic studies. In the natural environment, the aromatic compound's degradation ability is also active because of the interaction of microorganisms diverse in the environment (Simarro et al, 2013).

Pseudomonas, Ralstonia, Sphingomonas, and various other genera are among the well-reputed degraders of aromatic compounds. (Lee and Lee 2001; Coronado et al, 2012; Arora et al, 2014). The strains of the above-mentioned microorganisms are usually capable of degrading anthropogenic compounds which were recently synthesized; however, when talking about *Acinetobacter* strains, they usually can vitiate such aromatic compounds that contain solely natural products mainly from plants origin (Parke and Ornston, 2004; Young et al, 2005). During the catabolism of several aromatic compounds, many intermediate metabolites like catechol and protocatechuate and catechol, feeding the pathway of β-ketoadipate are produced. Several strains of environmental origin like *A. baylyi, A. calcoaceticus, and A. oleivorans* DR1) and pathogenic species like *A. baumannii* have pathways of catabolic metabolism for various aromatic compounds, sideways with the β-ketoadipate pathway, with almost similar syntenic planning. This property was reflected by sequencing data of genomes and comparative genomic studies. (Jung et al, 2011a). Aromatic compounds biodegradation can occur in contaminated soils, river or sea water (AlAwadhi et al, 2002; Hashizume et al, 2002; Ruzicka et al, 2002), or in the air (Juteau *et al*, 1999; Zilli et al, 2000).

Acinetobacter also has the property of degradation of hydrocarbons, particularly regarding alkanes of multiple chain lengths. Members of the genus *Acinetobacter* are often found in various sites of hydrocarbon contamination, including soils, Antarctic marine sediments, mangrove sediments, and pristine environments, which showed that *Acinetobacter* has the prospective for degradation of alkanes (Kuhn et al, 2009; Kang et al, 2011; Rocha et al, 2013). Different strains of *Acinetobacter* isolated have applications in the biodegradation of a variety of compounds, such as phenols, toluene, cresols, cyclohexane, furan, and lignin and lignocellulosic hydrolysate containing phenolic compounds (Vasudevan and Mahadevan, 1990, Jain et al, 1997; Lopez et al, 2004), acetonitrile, polychlorinated biphenyls (PCBs) (Rojas-Avelizapa et al, 1999), polymers and acrylic oligomers (Kawai, 1993), dichloroethenes (Olaniran et al, 2004), 4-chlorobenzoic acid (Kobayashi et al, 1998), and polycyclic aromatic hydrocarbons (Yu et al, 2005), because these strains have an extensive range of metabolic versatility (Towner, 1991b). For a better understanding of hydrocarbon degradation, some areas need to be studied further such as various environmental factors, sensing and signaling of substrate, and several other genetic factors in *Acinetobacter* spp.

2.4 Removal of Phosphates from Wastewater

Treatment of wastewater for the removal of Phosphate is a basic step of any sewage treatment facility because phosphate accumulation can result in eutrophication. Because of the frequent isolation of *Acinetobacter* spp. from activated sledges, it is considered that the concerned organism plays an important part in phosphate removal from wastewater by biological treatment. This property of phosphate removal is dependent on the activated sludge enrichment with polyphosphate accumulating sternly aerobic *Acinetobacter* sp. Auling et al in 1991 and Wagner et al in 1994 also mentioned that *Acinetobacter* as the main microorganism accounted for phosphate removal biologically (Auling et al, 1991; Wagner et al, 1994).

3. Oil Degradation

Various ingredients of oily sludge are found to be potent immunotoxicants and carcinogenic. Alkanes, aromatic compounds, asphaltene fractions, and NSO (nitrogen-, sulfur-, and oxygen-containing compounds), together make a complex mixture of oily sludge. Unprocessed oil results in several threats during environmental release. Many toxic compounds which are present in unprocessed oil, include aromatic polycyclic hydrocarbons, benzene, and its substituted cycloalkane rings. When these compounds are present in comparatively high amounts, they can cause physical, chemical, and biological damage to the marine environment. Among various microorganisms, *Acinetobacter* strains are thought to be the most competent oil degraders.

4. Stabilization of Bioemulsans and Oil-Water Emulsions

All bacteria which are hydrophobic in nature can stabilize oil-water emulsions. Two phenomenons were perceived for *A. venetianus* RAG-1 which were possibly liable for the emulsion gel structure including strong interactions of the cell to cell and the strong binding between the oil droplets and cells (Dorobantu et al, 2004). Also, the production of bioemulsans by *Acinetobacter* spp. is accountable for the emulsifying and biosorption properties of *Acinetobacter* spp. Several species of *Acinetobacter* also inhibit the property to produce polymeric Bio emulsions or Biosurfactants. Considering bio emulsions production by multiple Acinetobacter strains, the best-known examples are emulsan, alasans, and biodispersan, which have a key role in many industrial applications.

The main composition of bio emulsions produced by various *Acinetobacter* strains includes heteropolysaccharide, protein-polysaccharide complex, lipoglycan, proteoglycan, lipoprotein, and lipo-hetero-polysaccharide in environments. *Acinetobacter* spp. utilizes ethanol, crude oil, methylnaphthalene, n-hexadecane, glucose, peptone, lactic acid, n-heptadecane, glycerol, edible oil, C-heavy oil, and olive oil, as a source of carbon. (Hayder, 2015, Zhao, 2016). Along with carbon source, another important parameter to enhance emulsifier production is nitrogen source (Zhao, 2016), and the most common nitrogen sources used for the production of bio emulsions are $(NH_4)_2SO_4$ and Na_2HPO_4. Other sources of nitrogen used for the production of bio emulsions are urea and ammonium hydrogen carbonate (Navon-Venezia, 1995, Phetrong, 2008). It is noteworthy that nitrogen and carbon sources not merely increase the production yield but they also affect the emulsification activity of Bioemulsans (Zhao et al, 2016, Amaral et al, 2010). The temperature range for the stability of Bio emulsions produced by multiple strains of *Acinetobacter* was found to be 20°C to 40°C (Patil & Copade, 2001). While the pH ranges from 3 to 12 results in the stability of bio emulsions produced by *Acinetobacter* spp.

In 2001, Ron and Rosenberg reviewed the biological functions of emulsions. They reported about the bioremediation and mentioned that the use of *Acinetobacter* spp. enhances the bioavailability of water-insoluble hydrophobic substrates like polyaromatic hydrocarbons. It is also reported that these species can also bind heavy metals. Clinically, bioemulsions produced by various *Acinetobacter* species play a role in surface attachment and detachment and also promote biofilm formation (reviewed in Ron and Rosenberg, 2001).

Because of their biological properties, Bioemulsifiers could substitute some of the chemically synthesized emulsifiers in bioremediation regarding enhanced oil recovery and clean-up of vessels and pipes contaminated with oil. These bioemulsifiers can also use as additives in cleaning products and formulations of laundry, in the food industry as emulsion stabilizing agents, and in pharmacy and cosmetics products (Martínez-Checa et al, 2007, Dastgheib et al, 2008, Franzetti et al, 2012, Zheng et al, 2012, Monteiro et al, 2013, Amaral et al, 2006, Luna-Velasco et al, 2007)

5. Alasan

Alasan is a bioemulsifier mainly produced by the KA53 strain of *A. radioresistens* which is isolated from soil contaminated with oil. It has a high molecular weight and is made up of three proteins (AlnA, AlnB, and AlnC) and polysaccharides. First protein AlnA showed OmpA-like protein properties and is accountable for the alasan,s activity of emulsification. (Toren et al, 2002a). AlnB is the second protein that belongs to the family of thiol-specific antioxidant enzymes which are also called peroxiredoxins. There is no emulsifying activity that is inhibited by this Recombinant AlnB protein but it can stabilize AlnA generated emulsions of oil-in-water. (Bekerman et al, 2005). In the growth cycle, alasan is mainly in bound form to the cells during the log phase while it is released into extracellular space during the stationary phase. This growth pattern is also inhibited by the emulsan.

In purified form, alasan increased the aqueous solubility and polyaromatic hydrocarbons degradation rates, this may be due to hydrophobic reaction between alasan and these substances. Until now, alasan is mainly used for research purposes such as the recombinant surface-active protein production from a definite gene. This recombinant protein helps to study the structure and function of bioemulsions for the very first time (Toren et al, 2002b).

6. Emulsion

The emulsion is a bioemulsion mainly produced by an oil-degrading microorganism known as the RAG-1 strain of *A. venetianus*. The main function of emulsion is to form and stabilize the interaction between oil-water emulsions and a range of hydrophobic substrates. It is a complex of proteins and polysaccharides. Structurally it has a backbone of polysaccharide which is usually unbranched along with side chains of fatty acid which are complexed to proteins. Among these proteins, functionally significant is an esterase (Bach et al, 2003). In the biodegradation of oil, better inhibitory as well as stimulatory effects have been stated after the pretreatment of substrates with purified emulsan. In a biodegradation comparison of untreated unprocessed oil by *Acinetobacter* with emulsan-treated oil, it was observed that emulsion treatment enhanced aromatic mineralization. It was also observed that the mineralization of linear alkanes as well as other hydrocarbons which are mostly saturated was reduced both by mixed bacterial populace and by pure cultures. The lack of physical interaction between cells and the hydrophobic substrate may be the reason for this inhibitory effect. Among different emulsions produced by *Acinetobacter*, the most efficient emulsan in removing hydrophobic compounds from soil slurries is produced by strain RAG- 1 of *Acinetobacter*.

The availability of bioemulsifier and their manufacturing cost chiefly defines effective applications and technologies for the utilization of emulsan. While discussing applications of Emulsion, it has been reported that in the petroleum industry, the emulsion has the property to reduce petroleum viscosity and viscosity of other products of petroleum during their transport through the pipeline by establishing heavy oil–water emulsions. It also plays its role in direct combustion with dewatering by synthesizing fuel oil–water emulsions (Zhao, 2014). In the food industry, Emulsion exhibits potential application as an emulsifier. It has been proposed that emulsion incorporation in toothpaste and mouthwash could considerably minimize the formation of dental plaque. Immunologically, Emulsion can activate macrophages in a dose-dependent manner, and for this reason, it could be used to boost the immune response to a vaccine as an adjuvant (Panilaitis et al, 2002).

7. Biodispersion

The role of biodispersion is to adhere to the surfaces and disperses inorganic minerals. Structurally, biodispersion has a comparatively low molecular weight average of 51,400 Da when compared with emulsion produced by different strains of *Acinetobacter* spp. In purified form, anionic polysaccharide was found to be the active component of this biodispersion. Limestone is extensively used in the production of various products like paint, paper, and ceramics. In the context of this, purified biodispersion has impending application in the above-mentioned industries too. In grinding limestone into fine particles, biodispersion addition results in two possible benefits. The first one is to enhance efficiency by minimizing the required grinding time by more than 50%. And second, is the production of more uniformly ground products. Biodispersan produced by strain *A. calcoaceticus* A2 has the unusual ability to disperse TiO_z and $CaCO_3$ in water and so this biodispersion is widely used in different industries such as paint, paper, ceramics, and textile industries (Busi et al, 2017).

8. Biodegradation of Halogens and Xenobiotics

Many of the Xenobiotics pollutants like phenol, benzene, styrene, and toluene along with halogenated organic compounds like polychlorinated biphenylls and pentachlorophenol are usually present in wastewater in impartially low concentrations. These pollutants may also exist in higher concentrations in the form of spills. They may also be present in larger amounts in the soil as well as in water at unrestrained industrial sites. Xenobiotics and halogens are among the highly toxic compounds and their disposal is extraordinarily difficult.

Various studies have reported the role of multiple microorganisms in phenol biodegradation. Different strains of the genus *Acinetobacter* are also among the phenol degraders. Such strains use phenol as a sole source of carbon and energy. In 2002, a study was conducted by Abd-El-Haleem et al, on different Egyptian ecosystems and reported that out of twelve phenol-degrader microorganisms, four species are closely linked to *Acinetobacter* (Abd-El-Haleem et al, 2002a). Among these four species, one specie has been used in different applications of environmental studies (Abd-El-Haleem et al, 2002c; Beshy et al, 2002).

Various *Acinetobacter* strains can metabolized different xenobiotic compounds like toluene (Zilli et al., 2001), 2-chloro-N-isopropylacetanilide (Martin et al, 1999), 4-hydroxybenzoate (Allende et al, 2000), benzoic and p-hydroxybenzoic (Delneri et al, 1995), 4-hydroxymandelic and 4-hydroxy-3-methoxymandelic acids, 4- chlorobenzoate and 3- chlorobenzoic acid into their respective benzoates. Certain strains of *Acinetobacter* also can consume biphenyls together with chlorinated biphenyls.

Moreover, certain *Acinetobacter* spp. found to be efficient in the thorough mineralization of mono-halogenated biphenyls. But such species are usually isolated from mixed cultures. Degradation of lignin and amino acids has also been reported by different strains of *Acinetobacter* (Buchan et al, 2001, Kahng et al, 2002; Kim et al, 2001).

9. Phenol Biodegradation

Phenol is organic in nature and a vital raw chemical used in the production of many products such as preservatives, fungicides, resins, and pharmaceuticals. Phenol is also important in the production of dyes, synthetic rubbers, synthetic fibers, and other important materials for industrial uses (Gheni et al, 2018; Sepehr et al, 2019). In the end, phenol, however, is released into the environment from choking plants and refineries with the sewage discharge, becoming an important environmental pollutant (Cetinkaya and Ozdemir., 2018). Phenol is a highly toxic and carcinogenic chemical that can burn the skin and damage tissues following exposure or ingestion. It has also been reported that phenol can cause diarrhea, blurred vision, and liver damage (El Gaidoumi et al, 2019).

As phenol can cause serious damage to the environment and humans, three methods physical, chemical, and biological have been suggested for the treatment of phenol removal. Among these methods, the biological method is considered the best one for reducing phenol pollution. The reason is that biological treatment tends to be more feasible and environment friendly (Singh et al 2018; Zhou and Nemati, 2018). Strains of *Pseudomonas* and *Acinetobacter* were found to be more effective microorganisms for this purpose. These degrading strains are well-known for the bioremediation of various water bodies contaminated with phenol successfully (Iqbal et al. 2018; Ke et al, 2018;)

10. Role in Experimental Research

Another important application of the genus *Acinetobacter* is possibly in the experimental research field. An example of this is ADP1 strain of *Acinetobacter* spp. has been used in genetics as well as in genomics studies and microbiology laboratories and the field of molecular biology as a model organism because it has metabolic versatility as well as an extraordinary tendency to endure natural transformation. Many field scientists generally considered the strain ADP1 a non-toxic and non-pathogenic strain, so it can be used in the laboratory training of undergraduates (Metzgar et al, 2004; Young et al, 2005). The capacity of *Acinetobacter* to undergo a natural transformation and its unique behavior in the environment make it be used as an ideal sensor/model system. This system can be used to detect horizontal gene transfer from animals, plants, or other microorganisms.

11. Byproducts from *Acinetobacter*

11.1 Biopolymer Production

The use of fertilizers and effluent discharge from industries has increased in recent years, which results in the accumulation of phosphate to higher levels in the water bodies. It is also noteworthy that phosphate is the bioavailable form of phosphorus. Accumulation of phosphate in water bodies leads to eutrophication and algal bloom. (Xu K, 2012, Mishra 2010) Biological treatment for the removal of phosphate tends to be much better than physical and chemical methods because it is more efficient and disposal is easy. (Cloete, 2001, Albertsen et al, 2012, Onnis-Hayden et al, 2011)

Acinetobacter spp. is identified to be a principal organism in high phosphorus-containing sludge. This specific organism also can produce biopolymers and biopolymers in turn have the property to bind phosphorus. For the bioremediation purpose of phosphate removal, the use of biopolymers has several advantages over the usage of live microorganisms. These include the stability of biopolymers over a vast temperature range and for this reason, biopolymers do not require any specific arrangements for handling, storage, and transportation, another advantage is that biopolymers can be reused after bound phosphate removal. Also, the biopolymers are non-toxic and biodegradable as well as easy to dispose off (Boswell et al, 2001, Sathasivan et al., 2009, Liu et al, 2006).

Multiple strains of *Acinetobacter* species also have the property to accumulate esters of wax, cyanophycin, and polyhydroxyalkalonic acids (Vinogradov et al, 2002, Krehenbrink et al, 2002; Pirog et al, 2002;). Such kinds of biopolymers produced from these *Acinetobacter* spp. are extensively used in the production of fine chemicals like candles cosmetics, coating, printing inks, and lubricants.

11.2 Bio-emulsifiers

Bioemulsifier structurally contains both hydrophilic and hydrophobic groups. These are extensively used in different industries such as cosmetic, food industry, agrochemical, and pharmaceutical industries. Several microorganisms including the different strains of *Acinetobacter* can synthesize a variety of bioemulsifier. The well-known and most studied strains of *Acinetobacter* for the production of "bioemulsans," are *A. calcoaceticus* BD4 *A. calcoaceticus* RAG-1 and *A. radioresistens* KA53. Different glycolipids like sophorolipids, rhamnolipids, and trehalose lipids, as well as several lipopeptides like polymyxin, surfactin, and gramicidin, are usually considered bioemulsifiers of low molecular mass. While examples of bioemulsifiers having high molecular mass comprise proteins, amphipathic polysaccharides, lipoproteins, lipopolysaccharides, as well as complex mixtures of such polymers. (Toren et al, 2001).

RAG-1 *A. calcoaceticus* strain is an essential strain for two different industrial applications which includes its characterization to grow on hydrocarbons and it also plays a significant role in the production of emulsion, which is a bioemulsifier of high molecular mass. The emulsion that is produced by the RAG-1 strain is chemically composed of proteins and a lipoheteropolysaccharide non-covalently linked complex. The polysaccharide, that is present in lipoheteropolysaccharide is called apoemulsion, which is about 990kD in molecular weight. Taylor and Juni in 1961 initially isolated *A. calcoaceticus* BD4 strain which can produce a huge polysaccharide capsule. When this capsular polysaccharide is released into the medium, a complex is formed between proteins and capsular polysaccharide which eventually becomes an active emulsifier. The amphipathic properties of emulsan BD4 derive from the complex of proteins with a hydrophilic anionic polysaccharide.

Another strain of *Acinetobacter* known as the KA53 strain of *A. radioresistens* produces alasan which is also a bioemulsifier. This bioemulsifier is 100 to 200 kD in molecular weight. Preheating at 60 to 90°C generally increases its emulsifying activity (Toren et al, 2002). Kim et al in 1996 reported a bioemulsifier known as mannoprotein produced by *Acinetobacter* spp. BE-254. Mannoprotein can produce stable emulsions with several hydrocarbons, waste oils, and organic solvents. For this reason, the respective emulsifier can also be used as an effective cleaning agent.

11.3 *Acinetobacter* as Bioreporter

Among different kinds of nano-technologies, bioluminescent bioreporter is the most promising because it is economically feasible and a real-time technique for the detection as well as monitoring of environmental contaminants. While talking about the composition of Bioreporters, it refers to live, intact microbial cells which have been genetically engineered. Due to this, the bioreporter in response to certain physical or chemical agents has to ability to produce measurable signals. The composition of bioreporter revealed that it is composed of a reporter gene like green fluorescent protein or luciferase and an inducible promoter gene. (Hay et al, 2000). For bioreporter construction, different types of catabolic genes along with their regulatory systems can also be used. Nevertheless, bioreporter made up of *Acinetobacter* spp. comprises the use of whole-microbial-cell, provides most promising applications than the conventional bioreporter host like *E.coli*. The reason is that the species of *Acinetobacter* have different physiological characteristics regarding survival and growth. These features permit the use of ADP1 bioreporters for exploring and detecting oil spills in soil and water environments (Zhang et al, 2012).

11.4 Polysaccharides, Lipases, and Polyesters

Different *Acinetobacter* strains can produce various extracellular polysaccharides of variable sizes which can be up to several million Daltons. These polysaccharides can comprise of D-galactose, 3-(L-2-hydroxypropionamido)-3,6-dideoxy-D-galactose, rhamnose, D-2-acetamido-2-deoxy-D-glucose, 3-deoxy-3-(D-3-hydroxybutyramido)-D-quinovose, S-(+)-2-(4'-Isobutylphenyl) propionic acid or lipopolysaccharide (Kunii et al., 2001). Additionally, certain strains of *Acinetobacter* also show the property to cultivate on ethanol and then synthesize exopolysaccharides known as ethapolan from ethanol (Johri et al, 2002; Pirog et al, 2002; Pyroh et al, 2002).

Different species of *Acinetobacter* are worth mentioning lipase sources. Several strains of *Acinetobacter* were found to be lipolytic and they are isolated from variable sources (Snellman and Colwell, 2004). The activity of lipase in *Acinetobacter* species can be stabilized or maximized by the presence of Ca2+ ions. This led to the correct configuration of the active site because of the presence of a Ca2+-binding pocket. Moreover, an enormous number of lipases produced by *Acinetobacter* have potential applications in different procedures such as esterification, hydrolysis, and triglycerides transesterification, and in the selective chiral synthesis of esters (Chen et al, 1999; Li et al, 2001).

11.5 Production of Carnitine and Adjuvants

Different species of *Acinetobacter* have been suggested for the production of several other chemicals such as immune adjuvants, single-cell proteins, carnitine, and glutaminase-asparaginase which is used in the treatment of cancer. It has also been used for manganese leaching from ores. Other important uses of various *Acinetobacter* spp. or their products include promoters for the growth of plants and bio-control agents for several fungal and bacterial plant pathogens. Another specie of *Acinetobacter* known as *A. iwoffi* has been suggested to be used as a sensitizer for allergy protection.

11.6 Biosensors

Different *Acinetobacter* species have been broadly used as a biosensor. An example of this is, ADP1 which was used as a microbial sensor to detect sumithion, pesticide metaphos, and PNP in aqueous media (Guliy et al, 2003). It is also used as an indicator of *planta* bioluminescent which is non-destructive in nature and used for the production of methylsalicylate and salicylate. These two compounds are a part of the response system of plants against pathogens and are fundamental in acquiring systemic resistance in plants (Huang et al, 2006). A DF4 strain of *Acinetobacter* was nominated as bioluminescent biosensor in the form of whole cells and its role is to check heavy metals toxicity in water and wastewater (Abd-El-Haleem et al, 2006).

11.7 Production of Biosurfactant

Another important feature of different species of *Acinetobacter* is the production of Biosurfactant, along with lipase production and usage as a bioreporter. These *Acinetobacter* derived Biosurfactants have several applications in different industrial products like biodiesel (Noureddini et al, 2005), therapeutical accessories (Ono et al, 2001), production of biopolymers (Gross et al, 2001), and of cosmetics (Kiyota et al, 2001; Satpute et al, 2010). Different *Acinetobacter* species are known to produce biosurfactants including *Acinetbacter* spp. D3-2 (Bao et al, 2014). Among different species, *Acinetobacter venetianus* is best known and characterized for this purpose.

Biosurfactant are reported to be more powerful chemical surfactants than bioemulsans because of various properties. These include higher biodegradability, maximum efficacy at very low CMC, capability to reduce surface tension, specific and selective activity at extreme temperatures, salinity and pH, and higher foaming ability, (Roy, 2017). Many scientists have reported the effective applications of BS in multiple industries, for example. Cosmetics, paint, textile, detergent, medical and pharmaceutical, petroleum and petrochemical, food, and beverages, (Bannat et al, 2000).

12. Conclusion

There are several applications of different strains of *Acinetobacter* in the removal of environmental pollutants as well as the treatment of hazardous waste. They are also known to produce many important bioproducts which are economically feasible too. Potential improvements are expected from the genetic engineering of *Acinetobacter* strains from natural environments with widespread applications in environmental and industrial use.

13. Declarations

13.1 Conflict of Interest

All authors declare that they have no conflict of interest.

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